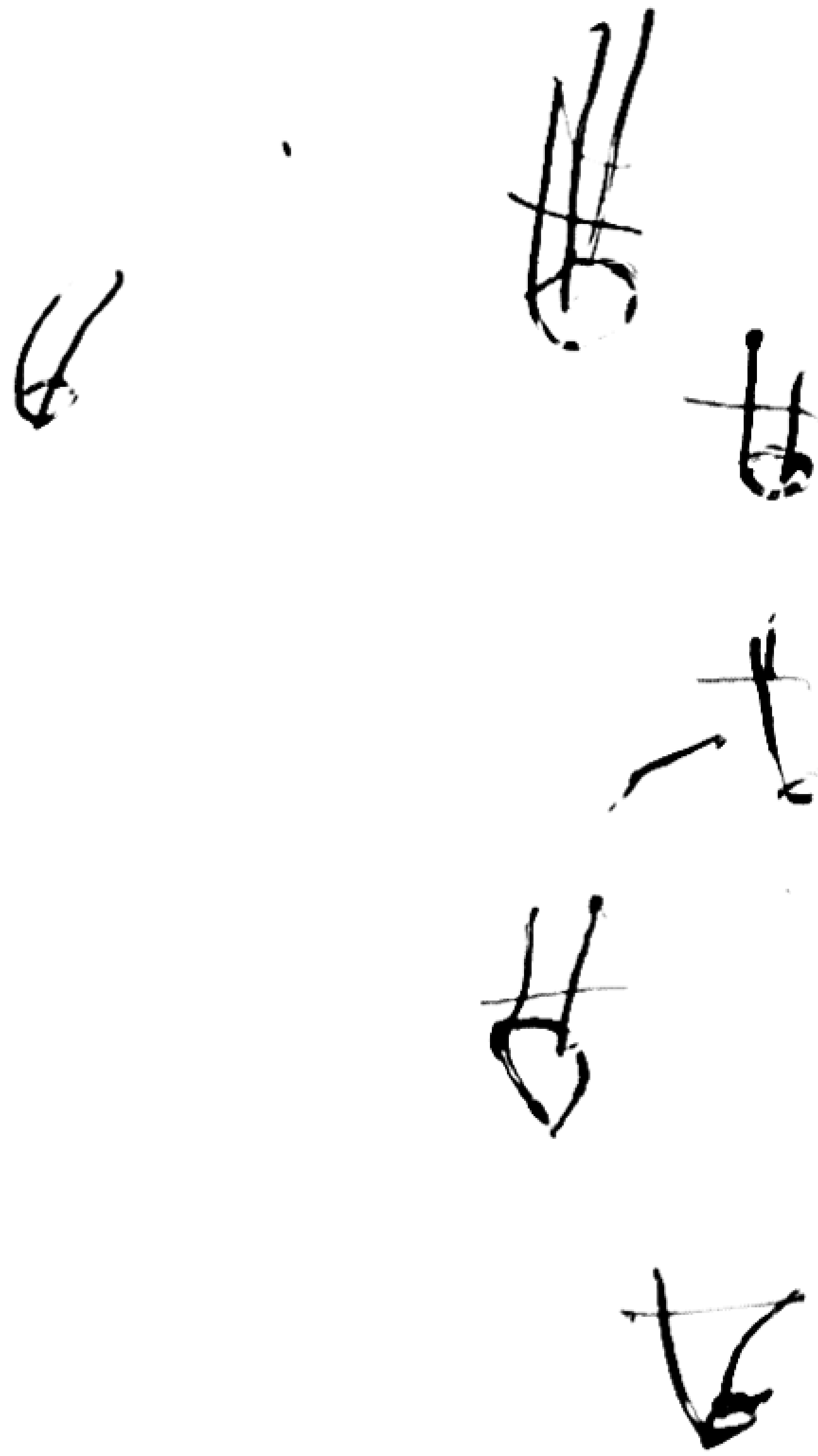
WEATHER IN THE MAKING



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CUMULUS, SMALL BUT VERY ACTIVE CONVECTIONALLY

To

DAVID FRANCIS STEPHENS

with my love

CONTENTS

CONTENTS

TABLES AND DIAGRAMS

ILLUSTRATIONS

INTRODUCTION

THIS GREAT GLOBE ITSELF

From earliest times weather has been of vital importance to man. Before ever he thought of crops the sun warmed and the rain wet him, ice froze and floods drowned him. When he herded flocks over the steppes he had to follow the pasture, which was abundant now in this region, now in that. From the dawn of intelligence he must have felt some rhythm about the ordering of these things, as wild creatures must still dimly feel it. It was a rhythm that suffered interruptions, but the sum of the interruptions went to its making.

When he conceived the idea of sowing and reaping

his desire to understand the rhythm became more urgent; he must be able to foretell the rainy season and the ripening time. He began to look to the stars for help; they in their courses could show him the circle of the year.

Astronomy is the oldest of the sciences. In the fourth millennium B.C. in the fertile valley of the Euphrates Virgo was already associated with the harvest. The Chinese, clustered round the Yellow River, and still ignorant of the use of metals, foretold the coming of the seasons by the stars. The neolithic Briton looked to the sun, and marked the turn of the year in stones so majestically arrayed that his primeval spirit still seems to brood darkly over them. The ancient Aztec raised a temple to the sun and carved therein his calendar, and long after he knew all that was to be known about the season for maize planting he watched every fifty-two years for the Pleiades to signal the end of the world. The early Greeks probably had their calendar from the Babylonians. Their weather they accepted from the lap of the gods. Zeus loosed a favourable wind in return for a becoming sacrifice, Athene filled the sails of her favourites, or Poseidon roused a hurricane against his enemies. If the moods of the gods could be foreseen the weather forecast could be made with confidence. Unfortunately the nature of the immortals was as incalculable as human

nature, and the most spectacular of sacrifices could not be relied upon with certainty.

Although the seasons and the length of the year were known in primitive times, man was hampered in any understanding of the weather by his conception of the universe. Day and night can conceivably be explained by movements of the sun, and the seasons by variations in his path across the sky, but a flat earth could bear no possible part in the coming and going of winds with their burden of clouds and rain. Aristarchus of Samos came near the truth in the second century B.C. when he suggested that the earth was a rotating sphere. He went on to argue that if this was so, then any point on the equator must be moving at a speed of a thousand miles an hour, and as any such movement would entail in those regions perpetual east winds of great velocity it was evident to him that his theory, however satisfactory in other respects, could not be correct. Had his knowledge of the upper atmosphere been more extensive he might have forestalled Copernicus by seventeen centuries.

Copernicus is the forerunner of the modern meteorologist, for without knowledge of the motions of the earth in space no understanding of weather and climate is possible. Wind, rain, sunshine, and even electricity in the air are ultimately ruled by the motions of the earth.

This being so, it may be as well to describe these motions shortly, before proceeding to the more terrestrial processes of weather making. Knowledge that has been carefully stowed away is apt to show signs of dilapidation when it has to be brought out unexpectedly for use.

The daily revolution of the earth from west to east through sunlight and shadow needs no enlarging upon. In the few centuries since Copernicus we have become so familiar with the conception that as we watch the red sun dip beneath the horizon we fancy ourselves moving, poised on the rim of earth and facing outwards to illimitable space. It is a thought born, not of observation, but of knowledge.

Of the earth's yearly journey round the sun we can have no direct experience. It swings in a vast ellipse, but an ellipse of such proportions that if it were reduced to visible dimensions it would appear to the eye as an exact circle. The earth is nearest to the sun, that is to say, in perihelion, during the summer of the southern hemisphere; farthest from the sun, or in aphelion, during the summer of the northern hemisphere, and the difference between nearest and farthest is about three million miles. Relative to the mean radius of the ellipse, which is 92,830,000 miles, this difference is small, and its effect on weather and climate is noticeable only in so far that summer in the

southern hemisphere is slightly warmer on the whole than summer in corresponding latitudes in the northern hemisphere.

If the earth were the only planet in the solar system and made a solitary journey round the sun, its path would be an exact ellipse, and the dimensions of the ellipse would be determined by the earth's velocity and by the force of gravity acting between sun and earth. But the force of gravity acts not only between sun and earth, but also between the earth and the moon and the other celestial bodies. It is an attraction exerted between all pairs of material bodies, whether large or small, and is proportional to the product of the masses of the bodies concerned, and inversely proportional to the square of the distance between them. Its effect is more evident between a large body and a small one, whether the bodies are the earth and Newton's apple, or the sun and the earth, but smaller and more distant bodies attract according to the same law. There are therefore slight variations in the earth's path, and these are due to the gravitational influence of the moon and the planets.

The motion of the earth that dictates the seasons is complex and in its entirety covers a long period of time. It is well illustrated by the type of top known to schoolboys as a dagger top on account of the long steel spike on which it spins. It is a difficult top to

master, but in the hands of an expert can be made to spin in smooth circles that suggest the path of the earth through space, and the long spike, extended in imagination through the centre of the top gives a clear idea of the earth's axis. It will be noticed that the axis of the top is rarely perpendicular, but generally slightly tilted, and in this position, whilst the top describes a sweeping curve, the axis sways, so that a point on the top of the wooden sphere describes a series of circles.

It is difficult to imagine a body as either perpendicular or horizontal when we think of it in space, but if we imagine a line drawn from the centre of the sun to the centre of the earth the axis of the earth could be called perpendicular if it were at right angles to that line. In that sense the axis of the earth like that of the top is not perpendicular, but is tilted at an angle of $23\frac{1}{2}$ degrees. This tilt does not remain the same. Just as a point in the centre of the upper portion of the top describes slow circles, so also do the north and south poles, and meanwhile the old earth nods a little, so that the circles are made in a series of waves. It takes about twenty-six thousand years to complete each one, but the effect of the movement can be observed even within historical periods. The Pole Star, for instance, has not always shone above the North Pole. With the help of the 'pointers' in the

and it was not until the Great Exhibition of the year 1851 that the first weather map was lithographed and sold for one penny per copy. Since then weather forecasting has made great progress, but it must be allowed to make much more before it can be expected to be accurate. All the information necessary to predict the behaviour of the earth in space is available, but all that is necessary to predict the behaviour of the weather is not at present available. Whether it will be by the time the science of meteorology is as old as that of astronomy it is much too early to say.

In the meantime this book is a modest attempt to give some account of the processes involved in weather-making, and the kind of information that is necessary to the production of a weather forecast.

I

THE EARTH'S ATMOSPHERE

Weather has no meaning apart from atmosphere. There are languages, indeed, in which air, wind, and weather are synonymous terms, and weather, when we come to think of it dispassionately—a difficult feat at most times—is nothing more or less than the atmosphere in its varying moods. It seems proper, therefore, to begin a study of the weather with some account of it.

The earth's atmosphere is composed of nitrogen, oxygen, water vapour, dust particles of various kinds, including micro-organisms, and a few other gases in very small amounts, all of which contribute in

proportion to the barometric pressure. The proportion of water vapour and dust varies very considerably, but the proportions of the other constituents, although slightly variable, are comparatively uniform. If dust and water vapour are left out of account dry air may be said to consist on the average of the following gases in the proportions given.

TABLE I

CONSTITUTION BY VOLUME OF THE ATMOSPHERE AT THE EARTH'S SURFACE

Gas	*Approximate Atomic Weight*	*Number of Molecules*
Nitrogen	14·0	78·03 in 100
Oxygen	16·0	20·99 „ „
Argon	39·9	0·94 „ „
Hydrogen	1·0	1 in 10,000 estimated
Neon	20·0	1 in 80,000 „
Helium	4·0	1 in 250,000 „
Krypton	82·9	1 in 2,000,000 „
Xenon	130·0	1 in 17,000,000 „
Carbon Dioxide, Ammonia		in small and variable quantities

The dust content of the air will be considered in more detail later on, for it plays an important part in the formation of cloud and fog. At present it is

sufficient to remark that dust particles are present everywhere, even over the oceans and up to great heights. There is reason to suppose that they are to be found more than fifty miles above the earth's surface.

There is no need to insist on the variability of the water-vapour content of the air, for it is quite evident to the senses, and so also is the fact that, on the whole, cool air tends to be dry and warm air has an uncomfortable habit of turning moist. Taken on an average over the whole surface of the earth the moisture content is about 1·2 per cent. It is highest in the tropics and in the monsoon areas, lowest over desert regions and over the Poles. With increase of height the proportion diminishes rapidly. Mountain air is noticeably drier than air at sea-level, and above the height of seven miles water vapour provides only ·01 per cent of the total number of molecules. However densely clouds seem to hem us in, it is but a short journey to get above them. But earth hugs us closely, and even with wings climbing is no easy matter.

If it were not for this pull of earth that makes us leaden-footed the atmosphere itself would fly off and be lost to us. It is held wrapped to the earth by the force of gravity, acting in a downward direction, that is to say towards the centre of the earth. The moon, because it is smaller, and its mass only one-sixth of

that of the earth, cannot retain an atmosphere. Possibly small quantities of the heavier gases, carbon dioxide and ammonia, drift around its surface, but these are incapable of supporting life. They are also insufficient to protect it from the sun's heat by day, or to retain this heat during the night, so it floats nakedly in space, alternately scorching and freezing.

At sea-level the atmosphere contains about $2{\cdot}6 \times 10^{19}$ (twenty-six million million million) molecules per cubic centimetre. With increase of height this number diminishes rapidly and half the total mass of the atmosphere lies below sixteen thousand feet. At twice that distance, however, the air does not come to a sudden end at the brink of empty space, as was believed little more than half a century ago. Air and space merge very gradually into one another, and the difference between them is of degree and not of quality, for space itself contains about one atom in every cubic centimetre. It is a tenuous region but not an empty one. Space is much emptier than what we know as a vacuum, but what we accept as a vacuum is only a vessel from which as much air as possible has been pumped. It may still contain as many molecules per cubic centimetre as 3.4×10^{10} (thirty-four thousand million), still a large number, but less overcrowded than in the open air.

The boundary at which the molecules that com-

pose the atmosphere cease to influence barometric pressure at the ground cannot be sharply defined, for in all probability some of the lighter gases fly off into space, whilst some of the heavier ones are still attracted to the earth by the force of gravity. This is contrary to the belief held until recently that above the height of about ten miles the various gases would distribute themselves according to their respective molecular weights, and that the proportion of the heavier gases, such as nitrogen (atomic weight 14) and oxygen (atomic weight 16), would diminish, and that of the lighter gases, such as helium (atomic weight 4) and hydrogen (atomic weight 1), would increase. This theory was founded on the suppositions that above this height the temperature was stable, and that no winds were present to mix the gases together as they are mixed by air currents near the earth. It has since been discovered that temperature is stable only in a layer of air about five miles thick, which may be called the stratosphere proper, and that even at great heights strong winds mix the various gases of the atmosphere in much the same proportions as they are mixed near the earth. Evidence is supplied by samples of air that have been secured in sealed containers by unmanned balloons up to a height of twenty-two miles, which show little variation other than a slight increase in the proportion of helium.

At still greater altitudes evidence as to the composition of the atmosphere is provided by Polar Lights. In order to find out more about their nature and their cause Professor Størmer, of Oslo, has taken many thousands of photographs of them, and by making simultaneous exposures at two different stations and then working out a calculation based on the distance between the stations and the position of the lights relative to their starry background he has been able to determine at what height they are wont to appear. According to these records the nearest the rays have approached to the earth is fifty-two miles, and the greatest height that has been recorded is over 680 miles.

Since light is invariably the outcome of the impact of some exciting agent with an atom, the appearance of Polar Lights establishes the fact that certain gases are present in these remote regions, and by means of the analysis of Polar Light spectra it has been possible to discover their nature. Both oxygen and nitrogen, the heavier gases, have been identified, and traces have also been found of helium and argon, but so far not a trace of hydrogen. It seems probable that this lightest of all gases has already slipped out of the earth's grasp and escaped into outer space.

Up to this point a great deal has been said about the nature of the atmosphere and its extent, qualities

that are not, on the whole, very variable, but little has been said about its pressure at the earth's surface, a more variable attribute that is of even more importance so far as weather is concerned.

Atmospheric pressure is frequently identified with weight, but the interchange of terms is convenient rather than accurate, for the pressure of a gas does not necessarily correspond to its weight. For instance, if a gram of air were confined in a football its pressure would be much greater than if the same mass of air were confined within a large balloon, but its actual weight would be the same. Its weight corresponds with its pressure only when it occupies an equal volume. Pressure is caused by the kinetic energy of gases, and this can be likened to the activities of a crowd of mosquitoes flying about inside a balloon. Sometimes they collide with each other, sometimes with the inner walls of the balloon. The collisions with the walls of the balloon constitute the pressure on it, and the more mosquitoes there are the more collisions there will be and the greater the pressure. The analogy may sound foolish, but it serves its purpose.

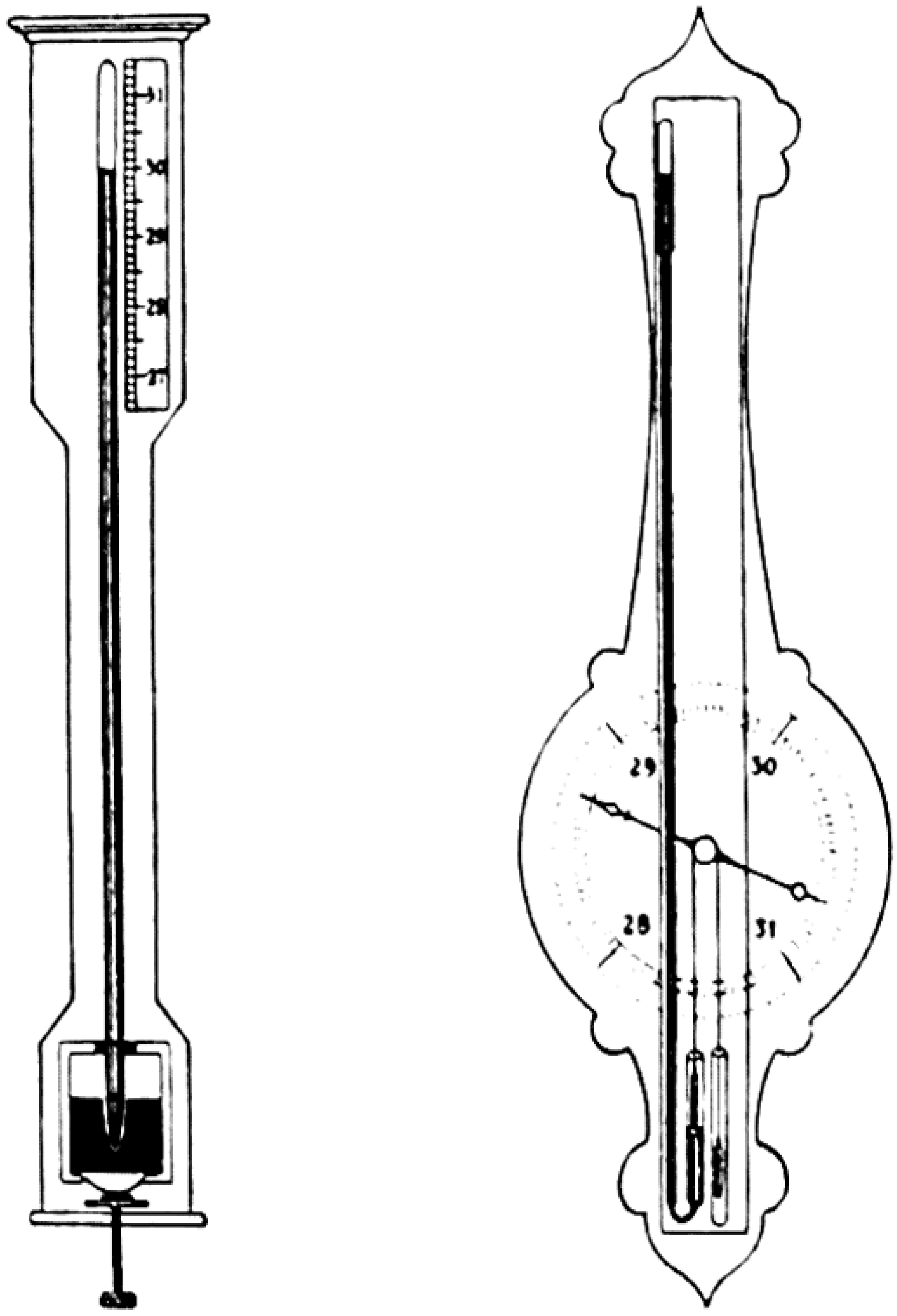
The force of gravity, acting between the earth and the molecules that compose the atmosphere, has the effect of concentrating the molecules near the earth's surface, and it is here that atmospheric pressure is greatest. As the distance from the earth increases the

molecules become less numerous and atmospheric pressure decreases. Nevertheless, in certain conditions it is possible for pressure to be greater in a higher level of air than in a lower one, a fact that makes the analogy between pressure and weight a little ridiculous.

Barometric pressure is measured by its effect as it presses upon the open end of a tube of mercury, in the mercury barometer, or upon the lid of a metal box, in the aneroid barometer. Although the construction of these instruments requires complicated calculations and careful adjustment the general principle on which they work is simple.

The average pressure of the air at sea-level supports a column of mercury of unit area about thirty inches high. If the barometer is placed above sea-level the air becomes less dense as the force of gravity decreases, and the pressure therefore decreases. As the force of gravity acts vertically downwards, towards the centre of the earth, pressure decreases as the distance from the centre of the earth increases. That is to say, pressure decreases according to height above sea-level, and not according to distance from the earth's surface. This is an obvious fact, but the reason for it is not always recognized. In practice, in order that readings may be comparable, barometric pressure is reduced to what it would be were the barometer at sea-level.

Mercury barometers are of two types. In the older model the mercury is enclosed in an evacuated J-shaped tube, closed at the long end and open at the short end. As the air increases in density the mercury



TWO TYPES OF MERCURY BAROMETER
(*By kind permission of Messrs. Negretti & Zambra*)

goes down in the short end and up in the long end, and as it decreases in density the opposite happens. In the more modern type a sealed tube inverted into a small bath of mercury takes the place of the J-shaped tube, and the effect is the same. In fact a similar result

is obtained if a bottle is placed upside down in an open vessel of water. The water rises inside the bottle when the atmospheric pressure upon the water in the open vessel increases, and when the atmosphere becomes less dense the water inside the bottle falls. Mercury is used in the construction of barometers rather than any other liquid because, on account of its great density (its atomic weight is 200), the height of the column required to support a normal atmosphere is of manageable proportions. Another advantage that it possesses is that it does not evaporate so rapidly.

The aneroid barometer measures pressure by the amount it depresses the lid of a metal box that has been partially evacuated of air. The lid is very thin, and is constructed in concentric corrugated circles in order to make it more elastic. Even so the effect of variations in pressure is small and has to be magnified mechanically several hundred times in order to make a record of convenient size. The aneroid barometer has obvious advantages of portability and compactness over the more clumsy mercury barometer, but the metal of which it is composed is sensitive to changes of temperature and as the adjustments are very delicate it readily becomes inaccurate.

The barograph, a familiar and too often a mysterious feature in the lobby of club or school, is in many ways the most interesting type of barometer of all, for

it shows both the minor fluctuations in pressure that go undetected by the ordinary barometer and also the tendencies in change of pressure that are so important in weather forecasting. Its principle is that of the aneroid barometer. A pin is pivoted in such a way that it rises or falls as pressure on a metal box—more often actually several metal boxes—increases or decreases, and traces a line on a paper chart wrapped round a cylinder that revolves by means of clockwork. This cylinder makes one revolution either in a week or in twenty-four hours.

It is wise to check barometer and barograph at regular intervals by comparison, if possible, with the standard instrument at the nearest meteorological station. Experience shows that meteorologists are friendly people, and a consultation with the meteorologist in charge would probably prove helpful. If the station is too far away comparison should be made with the readings published in the Press, due note having been taken of the hour and the position at which these are made. In any case a series of at least half a dozen comparisons should be made in order to calculate the mean difference.

Although the working principle of the barometer is simple its adjustment is more complicated. The density of mercury, for instance, like that of everything else, varies with its temperature, and therefore it is

necessary to state the temperature at which the weight of the column of mercury is equal to the normal pressure of the air. Again, the weight of mercury depends on the force of gravity exerted upon it, and this varies at different points on the earth's surface. The earth is not a perfect sphere, but has a slight bulge round its middle, and its diameter at any point through the equator is therefore 26½ miles (42 kilometres) greater than through the Poles. This is admittedly not very much in comparison with its mean diameter, which is 7,927 miles, but it is something, and it has the effect of decreasing very slightly the force of gravity in equatorial latitudes. On the other hand, centrifugal force, acting in the opposite direction, is greatest at the equator and zero at the Poles, for it acts outwards from the axis of rotation, and anywhere but at the Poles tends to throw a body away from the surface, and so make it very slightly lighter. As a consequence of the increase in the force of gravity and the decrease in centrifugal force an equal amount of mercury will weigh more if it is at the Pole than if it is on the equator, as will anything else, for that matter. A twelve-stone man weighs nearly a pound less when he is standing on the equator than he would if he were standing at the North Pole, even though he were of equal mass in either place. The force of gravity decreases, too, very slightly with altitude, but in the

lower levels of air with which the barometer is mainly concerned this decrease is almost negligible. Lest these adjustments should seem altogether too baffling it should be stated without delay that tables giving the corrections for latitude, altitude, and temperature can be obtained in England from the Meteorological Office of the Air Ministry, London, and in America from the United States Weather Bureau.

It has been calculated that a column of mercury 29·53 inches high, at a temperature of 0 degrees Centigrade (32 degrees Fahrenheit), in latitude 45° and at sea-level is equal to a pressure of exactly one million (10^6) dynes per square centimetre, a dyne being the unit of force necessary to produce an acceleration of 1 centimetre per second per second when applied to a mass of 1 gram.

In terms of weight this implies that at sea-level over an area of 1 square foot the atmospheric pressure is equal to about 1 ton. If the barometer rises 0·3 inches —to 29·83—the pressure is increased by about twenty pounds.

Owing to the international confusion between centimetres and inches (1 centimetre = 0·394 of an inch) pressure is now measured in a new unit called the millibar (mb.). One millibar is equal to a pressure of 1,000 dynes per square centimetre; 1,000 millibars is equal to a pressure of 1,000,000 dynes per square

centimetre, and to 29·53 inches or 750 millimetres of mercury, and is about the normal atmospheric pressure in temperate climates, where it usually varies between about 970 mb. and 1,030 mb. Readings as high as 1,050 mb. and as low as 925 mb. may occur, but they are exceptional.

Although millibars are taking the place of inches in barometric readings there are other terms, also no doubt originally suggested by the mercury barometer, that are still used in describing variations of pressure. We still commonly talk of a rising barometer, although we are well aware that, rather contradictorily, it is the pressure downwards in the open end of the tube that increases. And surely 'high' and 'low', though they now refer to pressure, originally described the position of the mercury. A high-pressure area, in which the atmosphere is dense and heavy, is designated shortly in the weather map by 'high', and is commonly known as an anti-cyclone; a low-pressure area, in which the air is less dense and lighter, is designated by the word 'low'.

And so, by devious ways, we have at last arrived at the deep depression that is such a prominent feature of the weather reports in the British Isles. Until recently it was frequently called a cyclone, but this word is now limited to the violent cyclonic storms characteristic of the tropics, and the more homely word is

used in describing the less extreme conditions common in temperate regions.

Isobars are lines joining places of equal barometric pressure, and isallobars, a word that is coming into more frequent use as its importance in forecasting is recognized, are lines joining places of equal barometric tendencies.

When selecting a position for the barometer it is necessary to ascertain the latitude and the height above sea-level of the building in which it is to be placed. A difference of one foot in altitude alters the reading by 0·03 millibars, and each hundred feet by three millibars, a considerable error. It is a mistake to place a barometer out of doors, for local variations of pressure are produced when the wind blows round an obstacle such as a house. A draughty hall has its drawbacks for the same reason, but if the wind does not blow directly into it, it has its advantages, for the barometer must be shielded from the heat of fires and radiators and from direct sunlight.

A high wind blowing over an open chimney reduces the pressure in the room beneath by creating a low-pressure area in the aperture in the top of the chimney. It also plays a greater part in causing the draught up the chimney than does the heating of the air below, a fact to be remembered when smoking grates are to be dealt with. Similarly, a wind blowing against a win-

dow during a gale will increase the pressure in a room, and in a room on the opposite side of the house will reduce it. Theoretically the difference due to a fifty miles an hour gale is about 3·3 millibars (one-tenth of an inch), but in practice it is never quite so high as this.

All things considered, a little-used room with a northern aspect is the best for the barometer, but if this is not available there is something to be said for the time-honoured position in the hall, where it may be tapped with impunity and consulted on the question of umbrellas.[1]

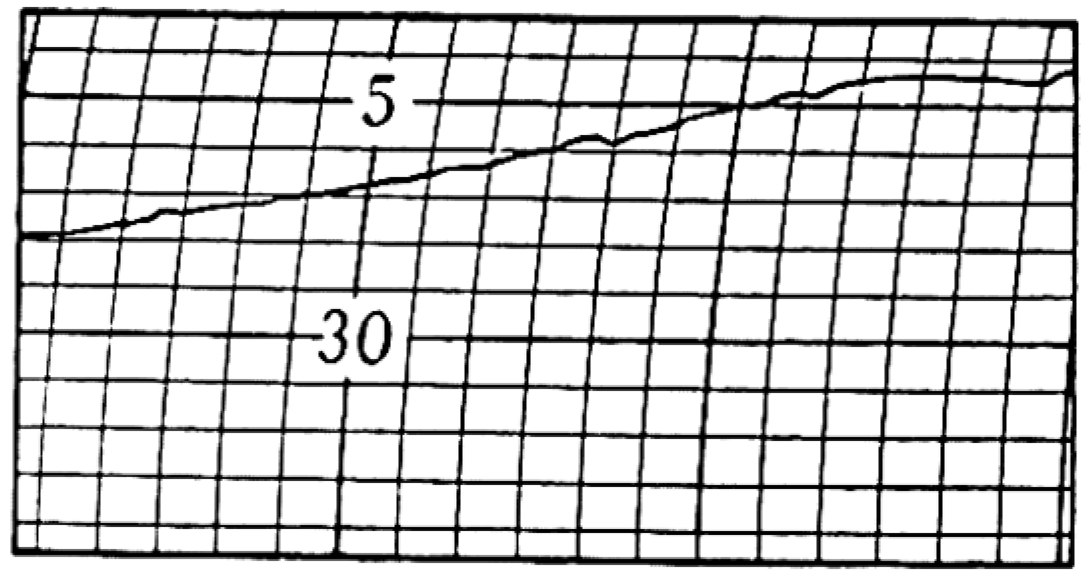
The generally accepted interpretation of the movements of the barometer in terms of weather is expressed by the traditional words on its dial—Rain, Change, Fair: if it rises it will be fair, if it falls it will rain, if it stops in the middle presumably the weather will remain in a constant state of change and nobody worries about the contradiction in terms. But it is obviously not as simple as all that. In fact the relationship between pressure and weather is so complex that it would be premature to embark on the subject at this point. Individual barometer readings must be interpreted in conjunction with the weather map, and particularly with reference to the position and probable development of pressure systems. The first

[1] For more detailed instructions *The Observer's Handbook*, published by authority of the Meteorological Office of the Air Ministry, should be consulted.

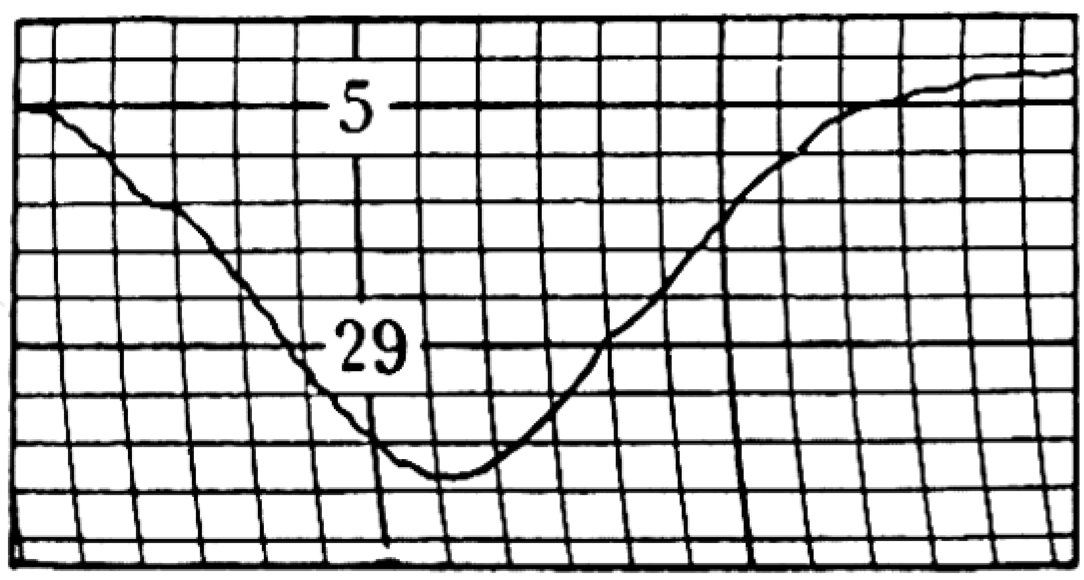
barometer, however, was constructed by Evangelista Torricelli in 1643, nearly two centuries before the issue of the first weather map, and mariners and such people interested in weather soon discovered its value. Practical experience proved its uses in forecasting, and these were defined with considerable accuracy long before modern theories had been elaborated. The best-known work on the subject was published in 1863 by Vice-Admiral Fitzroy, and is well worth mentioning, apart from its historical interest, for his observations have been largely justified by subsequently developed theories.

The Vice-Admiral himself is an interesting figure. His natural scientific bent was no doubt encouraged when, as commander of the *Beagle*, a brig of 240 tons, he was sent out to survey the coast of the Argentine and Patagonia, carrying as supernumerary, a certain Mr. Charles Darwin. The voyage lasted nearly five years, and his account of it, to which Darwin contributed a volume, was the standard work on those regions for many years. An interesting investigation of another type was entrusted to him in 1849, when he was given command of the *Arrogant*, one of the earliest screw frigates in the Navy, in order to make trials and experiments with a view to a general replacement of paddles by screws—the reason for the innovation being that paddle steamers did not lend

themselves to the accommodation of sails. But it is by his work as a meteorologist that Fitzroy is best remembered. In 1854 he was given the position of 'Meteoro-



BAROGRAPH CHART OF AN ANTI-CYCLONE
(Sunny in summer but probably foggy in winter)



BAROGRAPH CHART OF A DEPRESSION
(It approached suddenly and passed very rapidly, giving place to fine weather)
(*By kind permission of Messrs. Negretti & Zambra*)

logical Statist' to the Meteorological Department of the Board of Trade, and nine years later he published his *Weather Book*, in which his rules for the interpretation of movements of the barometer in north temperate latitudes were elaborated.

According to these rules a rapid rise of the barometer, contrary to the general impression, indicates unsettled weather; and a rise of the barometer whilst the thermometer is low and the air moist also indicates rain. Fair weather is indicated either by a gradual rise, or by a steady barometer with dry air and seasonable temperature. In summer a rise soon after rain, accompanied by dry air and a fall in temperature, will probably introduce better weather; and so also will a rise whilst the wind is in the south.

The longer a change is foretold by the barometer the longer it is likely to last, and conversely the shorter the warning the shorter will be the duration of the altered conditions.

A rapidly falling barometer indicates stormy weather; a fall after calm warm weather indicates rain or squalls; a rapid and considerable fall means rain or snow, according to season; a fall in winter with dry air and increasing cold foretells snow; and a fall with a northerly wind brings rain and hail in summer, snow in winter.

Fitzroy has a great deal to say about wind and the barometer, but this branch of the subject can be more profitably pursued later on, in connection with the development of depressions and anti-cyclones. The peculiar interest of his rules, and the reason for quoting them at this point, is that they were framed before

telegraphy had made the weather map generally available. It will be seen later how well they fit in with and are justified by the wider observations available at the present time.

In the old days, at any rate in the nursery, weather was foretold by a little weather house. On one side stood John with his tiny umbrella, on the other Joan, with her basket and parasol. When it rained—when it was going to rain we believed—John came out. Any weather was good enough for him. But when it cleared again he had to go back and keep house, and Joan popped out to enjoy the sunshine, as all good wives should. It was a magic house. To many of us it is so still. Even the knowledge that the little figures are worked by the stretching and shrinking of a piece of catgut as the atmosphere becomes moist or dry has failed to destroy its magic altogether. The barometer is in appearance a more prosaic affair, but it also has its charm. Hang one in the hall and see! And its charm is in no way diminished by a knowledge of its working. On the contrary it is increased. It becomes authentic magic as it balances the clouds and the invisible air around us. Nor is it likely to lose any of this magic when, in more detail, knowledge is gained how, and how far, it can be trusted to foretell changes in the weather.

II

TEMPERATURE AND PRESSURE

Atmospheric pressure varies both regularly and irregularly; that is to say, its variations are not altogether haphazard, but neither have they the mathematical precision of the alternations of darkness and daylight. Perhaps these changes are best imagined as a melody rising and falling within the limits of key and rhythm, as weather may be imagined changing within the general limits of climate and season. Music and weather have much in common. To those who love music and find weather trying the analogy will be unacceptable; but there are also those who dislike music!

Pressure and temperature are closely connected, but the connection is not a simple one. Pressure variations appear more erratic than the distribution of solar radiation would seem to account for, because they are due to more than one cause. If they are to be understood some knowledge is necessary of how the gases that compose the atmosphere behave when heated, and of how the surface of the earth is affected by solar radiation.

Air, like any other substance, expands when it is heated, and so reduces its weight relative to its volume. This is simply illustrated by the well-known fact that if a flask containing a cubic inch of air is connected with another flask of the same size from which the air has been pumped, the air in the first flask will promptly spread out and fill both. It then occupies twice its original volume, and as its total weight has not increased, the air in the original flask will weigh only half as much as it did before. When the temperature of the atmosphere is raised air spreads out in the same way and so becomes lighter, and as it becomes lighter it rises.

The first balloons had nothing more mysterious than hot air to raise them above the earth. It was sufficient to carry de Rozier and the Marquis d'Arlandes across Paris, although they had to maintain their supply of it by a wood fire suspended beneath the open

neck of the balloon and just above the wicker basket in which they voyaged. One of the airmen fed the legitimate fire with logs of wood, the other put out with wet sponges the illegitimate fires that kept occurring in the balloon's gear. It was a precarious proceeding, but a good example both of Gallic pluck and of the lifting power of hot air.

Air not only rises because it has expanded, but also continues to expand because it rises, for as it goes upwards the pressure around it decreases. This again can be illustrated by the behaviour of balloons. When a balloon leaves the earth it is, as a rule, only about half full of gas, and its limp envelope flaps about in the breeze like a loose sail. As it rises into regions of lower pressure the gas inside the balloon begins to spread out, and the balloon becomes pear-shaped. As the pressure outside continues to decrease in proportion to the pressure inside it becomes more and more round, until it is a hard, tight ball. If it has risen above the clouds the expansion inside will be still further increased by the heating effect of the sun, and if the envelope is not sufficiently strong the balloon will burst.

This close relationship, common to all gases, between pressure, temperature, and volume must always be remembered when air is in question, for it plays a very important part in weather-makin

Although the heating of the atmosphere is due to the sun, for the most part it is not, as we are apt to suppose, directly due to it. Just as light is invisible until it encounters something that reflects it, so heat is impalpable until it encounters something capable of absorbing it. When we look up into the night sky we see nothing of the sun's light streaming through space unless moon or stars lie in its path to catch it and reflect it back to us; and high above the clouds the sun's warmth, pouring through the upper atmosphere, leaves the air colder than anything that is experienced on earth.

Every preparatory schoolboy knows that it is colder at the top of a mountain than at its foot, but when asked why, he is usually put out, especially if he is slyly reminded that it is nearer to the sun. Kilimanjaro, on the equator, reaches high towards the sun, but for all that it is snow-capped. On the other hand in a room the hot air is always to be found near the ceiling—but it is there only because it cannot escape.

Dry air as it is composed near the earth's surface cannot be warmed appreciably by solar radiation. Heat from the sun passes through it in the form of electro-magnetic waves until it encounters some substance that is capable of absorbing it. Water vapour to a small extent, and water-drops to a larger extent, are warmed by solar radiation, but it is not until it

reaches the earth that it encounters any surface that can be warmed very effectively. Even so, different materials vary very much in their capacity for absorbing heat. On a hot day a stretch of sand becomes intolerably hot whilst a green lawn remains refreshingly cool; an iron roof becomes hotter than the sand, thatch is merely comfortably warm, and the deep sea may be still quite chilly. Temperatures taken in sunlight are of no value at all, for they merely record the temperature of the thermometer, and when it is placed in the sun that depends on the capacity of the material of which it is made for absorbing solar radiation.

Every substance that has been heated sufficiently to raise its temperature above that of its surroundings passes on the heat it has received both by means of conduction, through the substance itself, and by radiation, through the air. These radiations, however, are not identical with those it has received from the sun.

All electromagnetic radiations, X-rays, light rays, heat rays, wireless waves, and so on, are, as far as is known, of the same nature, but they differ in the length of their waves. Those of shortest wave-length are the wave components of cosmic rays, those of the longest wave-length are radio waves. Heat waves are short in wave-length compared with radio waves, but

long compared with light waves, and come next in order after the longest light waves, i.e. the red components of visible light. On this account they are sometimes known as infra-red, or dark radiation.

Heat waves are not all of the same wave-length, any more than light-waves are all of the same wave-length. The wave-length of light determines its colour, the wave-length of heat is determined by the temperature of the substance that emits it, and the hotter the substance is the shorter is the wave-length. It is the wave-length that determines whether radiation can be absorbed by substances with which it comes into contact. Light waves, for example, and to a large extent short heat waves, pass through ordinary glass just as they pass through dry air. Much of the heat from the sun passes through the roof of a glass-house and warms the clay flower-pots and wooden benches beyond, but of course the temperature of the wood and of the flower-pots never approaches anything like that of the sun, the heat waves they send out are therefore much longer than those they have received and cannot escape again through the glass roof. Consequently a glass-house becomes very much warmer than the air that surrounds it, although both receive the same amount of solar radiation.

When the very short heat waves from the sun encounter the earth a similar process goes on. They are

both reflected and radiated back into the air. Those that are reflected do not change their wave-length, but those that are radiated change in accordance with the temperature of the radiating substance, and are therefore of much longer wave-length than those emitted directly by the sun. These longer heat waves are more easily absorbed both by water vapour and by water-drops, and clouds and water vapour receive a very large amount of heat from below in addition to the very small amount of heat they receive from above. This heat in its turn is radiated in all directions, and there is a constant exchange going on between cloud and cloud, and clouds and earth.

Cloudless days are hot because the earth receives its full quota of solar radiation, but if, at the end of a summer day, the sky is still clear and the stars bright, we must prepare for a chilly night, for the earth's heat will radiate rapidly away into outer space. On the other hand, if clouds gather at sunset we shall need no other blanket, for they will keep the earth warm, catching its radiations and sending them back again in a night-long game of shuttlecock.

In sub-arctic regions, in northern Canada, in Russia and Finland, where the farmer wins a reluctant harvest from the soil during the brief summer, he watches the sky anxiously towards evening when his crops are ripening, hoping for clouds, for a clear night spells

ruin. If the heat escapes from the earth into starry space his crops will be withered by the frost.

The most extreme ranges of temperature are found in the dry climate of desert regions, where during the day solar radiation reaches the earth with the minimum of interruption from clouds and water vapour, and during the night is radiated away, again with a minimum of interruption, into outer space.

In addition to heating by direct and indirect radiation the presence in water vapour of what is known as latent heat adds, when it is released, its small quota to the heating of the atmosphere. Energy—and heat is a form of energy—is indestructible. It can be changed into matter, as, in the opposite direction, matter can be changed into energy, or it can be lost in space, where there is room for much voyaging, but it cannot cease to be. This is one of the most profound doctrines of modern physics—that there is no annihilation, only change. The expression 'the annihilation of matter' is inaccurate, for when matter, which is one form of energy, is metamorphosed it does not become nothing, it becomes another form of energy, and this again is potential matter.

In order to change the state of a substance energy is required, whether it is ice that is to be changed into water or water into vapour, and during the change of state constancy of temperature is maintained. When

ice is heated its temperature does not rise above freezing-point until it has become water, and when water is heated its temperature does not rise above boiling-point until it has become vapour. To change 1 gram of ice into water at 0° Centigrade (32° F.) 80 calories are required, and this same amount of heat would be sufficient to raise the temperature of 1 gram of water at 0° Centigrade to 80° Centigrade. To change 1 gram of water at 100° Centigrade into vapour still more heat, viz. 538 calories, is necessary. This energy is stored, in the first case in the water, in the second in the vapour, without raising its temperature, and is known as latent heat. When the change of state is reversed, that is to say, when water is turned into ice or vapour into water, the latent heat is released and becomes again available.

Most of the energy used up in evaporation from seas, streams, lakes, and moist surfaces is derived from solar radiation, some is derived from the water itself, and some from the air.

The loss of heat to the air through evaporation is demonstrated by the instrument used to gauge the humidity of the atmosphere, namely the psychrometer. This instrument consists of two thermometers, an ordinary, or dry-bulb thermometer, and a wet-bulb thermometer. The bulb of the latter is kept moist by a piece of damp muslin secured by a string

the other end of which is dipped in a vessel of water. Evaporation from the muslin covering cools the air in the immediate neighbourhood of the wet bulb and the temperature registered by this thermometer is therefore usually lower than that registered by the dry-bulb thermometer. When the surrounding air already contains a relatively large quantity of water vapour there will be little further evaporation into it, and the difference in temperature registered by the two thermometers will be slight. When the atmosphere is relatively dry evaporation into it will be rapid, and the difference will be proportionately increased. When the surrounding air is completely saturated no further evaporation will take place and the readings of the two thermometers should be identical. The relative humidity of the atmosphere, the dew point, and the water-vapour pressure that correspond to the readings may be obtained from hygrometric tables, issued in pamphlet form by the Meteorological Office.

Unfortunately the instrument cannot be considered absolutely accurate as, up to a point (i.e. a speed of ten miles per hour), the rate of evaporation is conditioned by the volume of air into which it takes place —in plain terms, by the speed at which the air circulates around the thermometers. This difficulty is overcome both by the whirled psychrometer which is used

in America, and by the aspirated (or Assmann) psychrometer used in Germany, in which the air is kept moving past the thermometers by a clockwork fan.

A more familiar use of the process of cooling by evaporation is made in hot countries, where wet curtains are hung in passages to cool the surrounding air. Even in temperate climates doctors and nurses would do well to remember this process during spells of hot weather. Wet cloths hung in a sick room or ward, out of the direct sunlight, will appreciably lower its temperature and so diminish the discomfort of the patient.

The energy or heat, whatever its source, that is used up in evaporation is not permanently lost. It is given up again to the atmosphere when the vapour is changed back again into water by condensation. Thus the formation of clouds contributes to the warmth of the surrounding atmosphere.

In cooling the atmosphere the most important factor, and the one that is mainly responsible for its decrease of temperature as altitude increases, is known as dynamic cooling, and is the cooling consequent upon the sudden expansion of air. The same process is at work when the valve is removed from a bicycle tyre. Inside the tyre the air is compressed, but immediately it is released it expands rapidly and becomes noticeably cooler. In the atmosphere expanding air not only cools but also rises, and so the process of

expansion and cooling goes on until it has become equal in density and in temperature to the air around.

Another important factor in the cooling of the atmosphere has already been mentioned; it is the radiation of heat into space. What becomes of it then it is impossible to say, but at all events it is lost to the earth.

Heat may also be lost to one section of the air by conduction, i.e. by being shared with neighbouring air, a process that tends in the atmosphere, as in everything else in nature, to produce a uniform temperature.

It might be well, at this point, to sum up the methods of heating and cooling, so that they may be compared at a glance, like a simple sum in addition and subtraction.

The heating processes consist in:

1. Long-wave radiation from the earth.
2. Long-wave radiation emitted by the earth and radiated back by clouds and moisture.
3. Radiation from clouds and moisture derived originally from direct solar radiation.
4. Latent heat released from water vapour by the formation of water-drops.

The cooling processes are:

1. Dynamic cooling.

2. Loss of heat by radiation into space.
3. Loss of heat from one portion of atmosphere to another.

As a net result of these combined processes air of average humidity that is actively rising cools at the rate of about one degree Fahrenheit in every 187 feet, or one degree Centigrade in every 100 metres. This decrease in temperature is slightly more rapid than that actually occurring in the atmosphere itself, such as it is when not actively rising, and therefore rising air, with its more rapidly decreasing temperature, must eventually arrive at the same temperature as the air that surrounds it and there come to rest.

It is a striking testimony to the complexity of the calculations involved that, in spite of the tremendous scientific activity of the last century, this fact was not deduced from theory. The general belief, held until 1898, was that the fall of temperature continued indefinitely to the limit of the atmosphere, and when in that year Tessereinc de Bort, as the result of records obtained by sounding balloons, made the discovery that at the height of about ten miles it ceased he was not at first believed. But the evidence was reliable, and it was eventually found that the theories outlined above accounted satisfactorily for the discovered facts.

The region in which the fall of temperature is, on

an average, proportional to height is known as the Troposphere; that in which height does not affect the temperature is the Stratosphere. Dividing the two, a fluctuating region, is the Tropopause.

The troposphere is the familiar region of the atmosphere; in it the clouds float, the rain is begotten, and the familiar winds blow. Until the present century its boundary was as much the edge of the world as the river Styx was to the ancients. But the Heroes are not dead, and we also have our adventurers who have crossed this mysterious boundary and have brought news of the tenuous tract beyond.

Owing to the varying quantities of water vapour in the air the height of the tropopause changes from day to day and is different in different latitudes. Where the air normally contains a large quantity of water vapour and clouds are frequent the contribution made by the release of latent heat to the temperature of the atmosphere is greater than where the proportion of water vapour is small and clouds are less numerous, and as a result of this extra contribution the air continues to rise after it would otherwise have come to a standstill. Consequently in tropical regions where the amount of cloud is greatest the height of the troposphere is greatest, and the upper limit of the tropopause is about ten and half miles. In temperate latitudes it is about seven miles high,

and over the Poles, where the moisture content of the the air is least, it is lower still.

The temperature of the stratosphere is not absolutely uniform. It varies from day to day and from season to season, and it also varies with latitude. Oddly enough it is warmer—if one may use this word in describing temperatures of -60 degrees Fahrenheit—in higher latitudes, where on an average it is about -67 degrees Fahrenheit (or -55 degrees Centigrade), and colder—this word is used with confidence—above the equator, where it is about -95 degrees Fahrenheit (or -70 degrees Centigrade). It is sometimes even colder than this, and a temperature of -134 degrees Fahrenheit has been registered above Batavia (lat. 5·40 north) at a height of ten miles. This is about 40 degrees Fahrenheit lower than any temperature that has been registered at the earth's surface.

The human mind has a tendency to believe in the continuance of its own experience, and even the scientific mind is not altogether untouched by this human weakness, for when belief in the continuity of convection had been reluctantly abandoned its place was taken by a belief in the boundlessness of the stratosphere. This belief again had to be relinquished, for further soundings have demonstrated that at an altitude of about sixteen miles the tempera-

ture of the atmosphere begins to rise again. For some time the reason remained a mystery, but eventually it was discovered in the presence of ozone.

Up to this point the varying capacity of different gases for absorbing radiation has not been mentioned. About one-half of the total amount of solar radiation that meets the earth's atmosphere is absorbed before it can reach the earth itself, but it is not equally absorbed at each level, nor is its absorption proportional to the density of the air. The gases composing the atmosphere are selective, and some absorb more of certain wave-lengths than of others. Both ozone and oxygen absorb a great deal of short-wave radiation and emit very little, and the result is that at levels where these gases are proportionally more abundant the temperature of the atmosphere rises. It is probable that at a height of thirty miles it reaches more than tropical heat, but whether temperature at this height can have any effect on pressure at sea-level is doubtful.

Ozone alone is responsible for the absorption of 5 per cent of the solar radiation that encounters the atmosphere. This consists mainly of the ultra-violet rays that are so necessary to health, and of which an overdose would prove fatal. The answer to Rosalind's 'Can one have too much of a good thing?' although her Orlando was cunning enough not to give it, is 'Yes, Madam, undoubtedly.' Too much of ultra-

violets and life would come to an end on the earth, but too little, and a similar result is achieved by the slow process of rickets and tuberculosis. We owe much of our comfort to this layer of ozone, and it is a far more effective protection than either the chest-protector favoured by our grandmothers, or the sun-burn creams that our grandchildren have adopted in its place. And yet it is not what we should think of as a large quantity. If it were collected and brought down to sea-level—that is to say at atmospheric pressure—it would make a layer about one-seventh of an inch thick in the neighbourhood of the Poles, where it is most abundant, and only one-sixteenth of an inch at the equator, where there is less of it. Most of it is distributed between fourteen miles and twenty-two miles above the earth.

In addition to its action as a protective screen, the ozone layer has some effect, as yet imperfectly understood, on changes in the weather. It has been discovered that regions of high concentration of ozone follow a little behind and far above areas of low pressure, and that regions of low concentration of ozone follow above and a little behind areas of high pressure. It seems that, although the stage on which the weather plays its part is in the lower layers of the atmosphere, high above the stage are prompters and scene-shifters directing the course of the action. The

effects they produce can be watched, but their methods are obscure and can only be guessed at.

And now it is time that the imagination that has been allowed for a moment to soar amongst the stars should be recalled to consider the effect of barometric pressure in air that is wrapped more closely about the earth.

III

WIND

Wind is simply the movement of air away from areas of high pressure and towards areas of low pressure. The atmosphere is never stagnant. It is a maze of rising and falling currents, of streams without banks, of whirlpools and cataracts, of oceans without shores. Even on a still day the earth breathes, softly, like a sleeping child.

But this amazing commotion is not without system, and the Ariel that finds himself free as air must next discover that the air itself enjoys only an ordered freedom. Its coming and going is determined in the first place by the distribution of zones of low and high

pressure, and in the second place by the turning of the earth.

The principle of wind circulation between zones of low and high pressure can be illustrated by the circulation of water between two jars when the water in one of them is heated. The jars are connected by two pipes, one at the bottom, and one, closed by a tap, near to the top. The heating of the water in one jar causes it to expand and rise, and has the effect of increasing the pressure near the top. On account of the increase of pressure above, if the tap in the upper connecting pipe is opened, water will flow through it from the warm vessel into the cool one. This will decrease the pressure in the lower part of the heated jar, and water will flow through the lower pipe from the cool vessel to the warm one.

Air behaves in the same way. When it becomes heated at the earth's surface pressure decreases in the lower levels and increases in the upper levels. Near the earth air flows in from regions of higher barometric pressure, and in the upper regions it flows out. The principle is most simply illustrated by the sea breeze, which has its origin in the unequal capacity of land and water surfaces for absorbing and radiating heat.

It has already been remarked that on a hot day land becomes warm rapidly, whilst the sea becomes

warm slowly. Its surface is constantly changing, and before one layer has been heated to any extent it is whisked away by the constant ebb and flow of water currents, which may carry it either down to the cool depths or away to some less sunny quarter. On a bright day a shallow creek and the wave's edge are always warmer than the sea itself, for they are heated by radiations from the ground beneath, but even so they are much cooler than rock or sand. This must be so, for the amount of radiant energy that raises the temperature of a cubic foot of rock by 4 degrees Fahrenheit will raise the temperature of a cubic foot of water by only 1 degree Fahrenheit.

Once the sea is warmed, however, it keeps its warmth much longer than the land does. A bathe on a warm day in June is a chilly affair; it is much better to wait for a cool day in October. Both sea and land lose heat through the processes of evaporation and conduction, but whilst the land loses heat with amazing rapidity by the process of radiation the sea loses it by this process very slowly indeed. The contrast is so great that two hours after sunset the sandy shore is already cold to the touch of naked feet, but the sea keeps pleasantly warm all night.

The effect of the heating of the land during the day is to induce a sea breeze near the coast, and, in a less degree, the consequence of its cooling at night is to

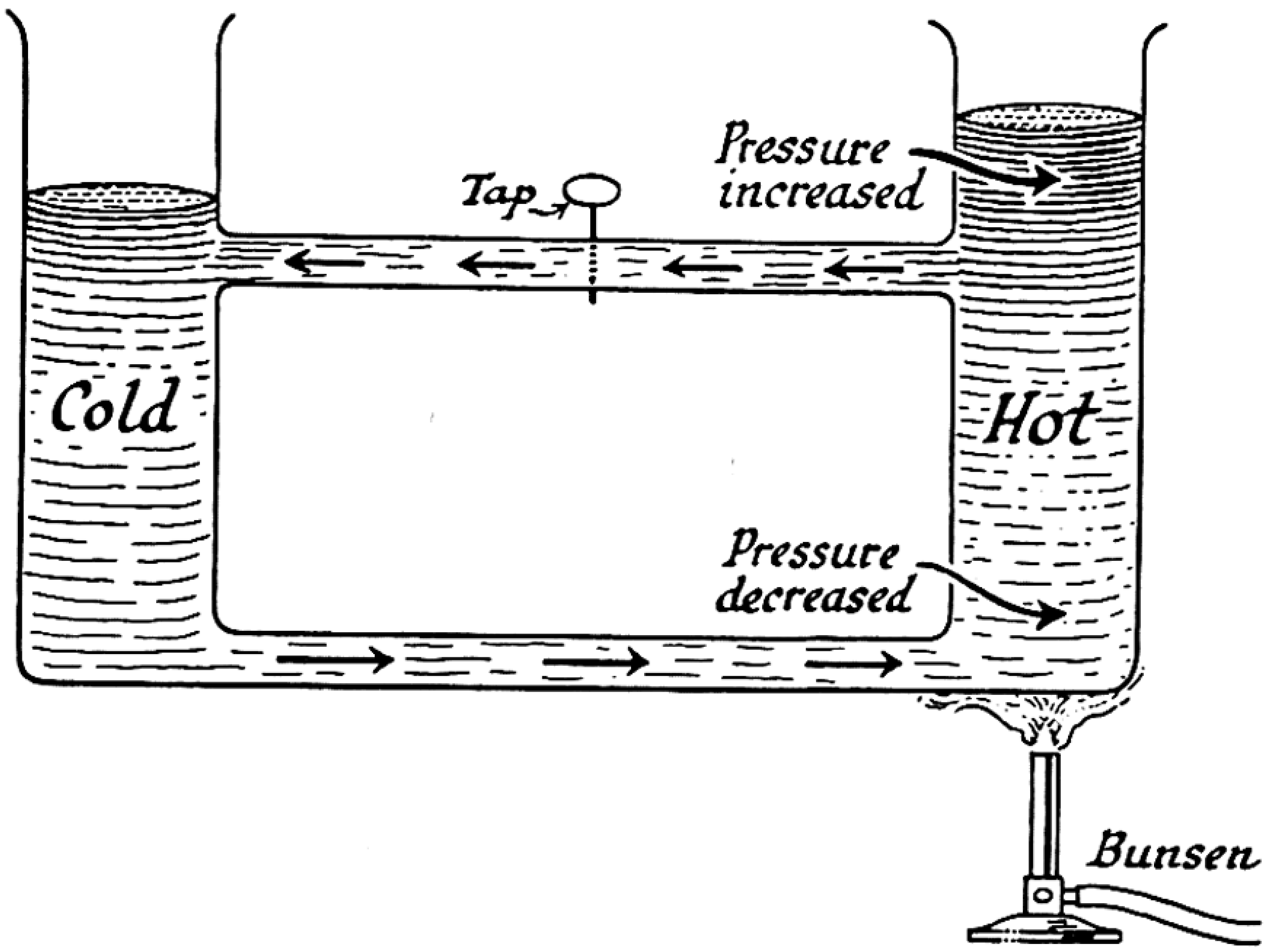


DIAGRAM ILLUSTRATING THE CIRCULATION OF WATER WHEN HEATED

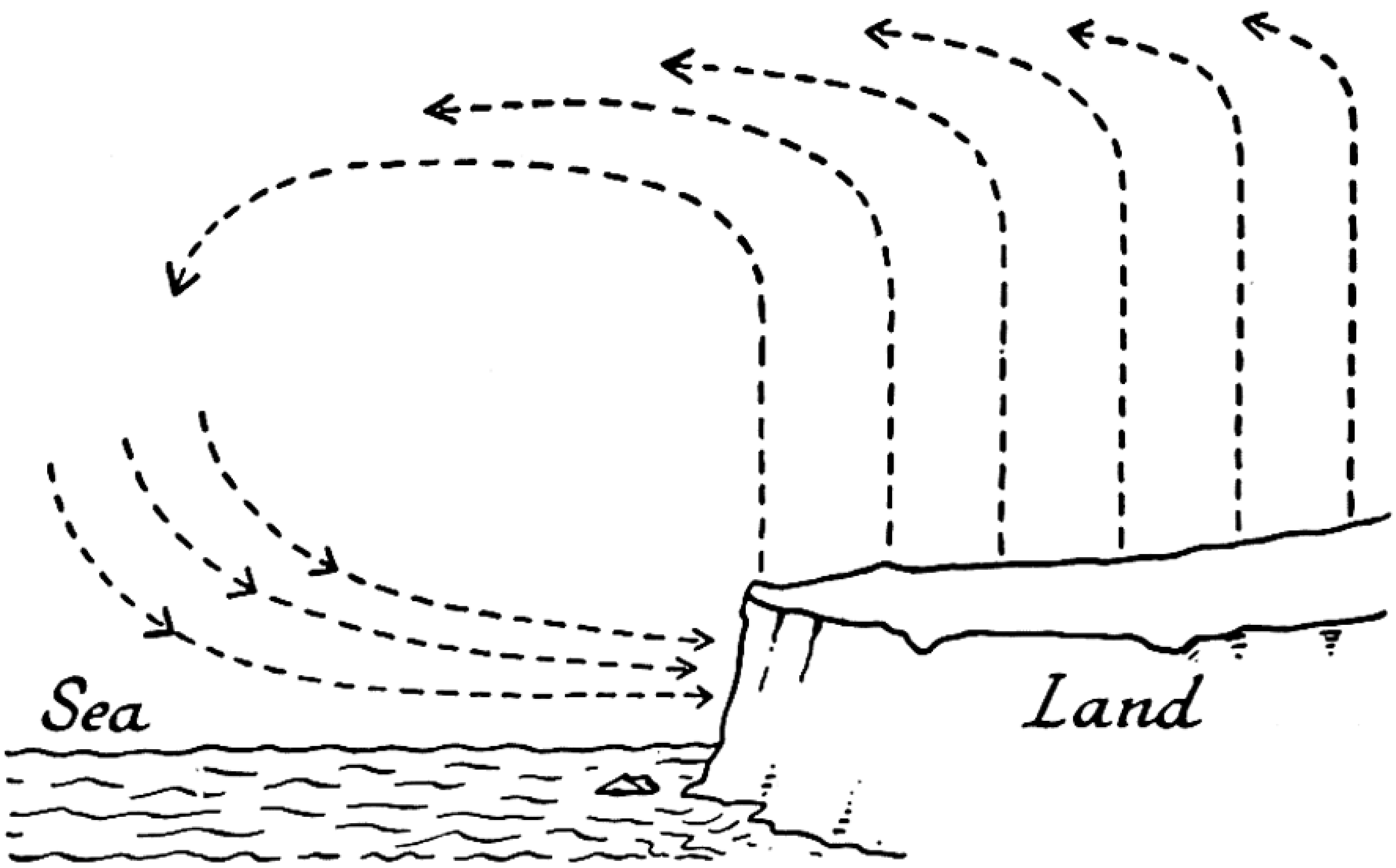


DIAGRAM ILLUSTRATING THE CIRCULATION OF A SEA BREEZE

induce a land breeze. In both cases the air behaves like the water in the jars. As the land grows warm during the day the air rises, the rising current increases the pressure in the upper regions until it becomes greater than pressure in the corresponding layer over the sea, and consequently overflows. Meanwhile the pressure at sea-level has been reduced and is less than that of the corresponding layer of air over the sea, and this cooler air flows towards the land in the form of a sea breeze.

It is this daily inflow of cool air from the sea that is responsible for the extreme tanning effect of the sun at the sea coast, for short-wave radiations, to a large extent absorbed by water vapour, penetrate more freely through the cool dry air than through the warmer, moister air above inland districts. Inland the same sun-tanning effect is observed at great heights, where the vapour content of the air is also greatly diminished.

Recent gliding experiments have shown how very persistent the sea breeze can be even in the face of a wind blowing in the opposite direction. On more than one occasion it appeared to break in the form of a great roller over the cliffs of Devonshire, where it formed a gigantic bolster across the path of an anticyclonic wind blowing from the north-east. The land wind was forced to mount, at a steep angle, over the

sea wind, and so provided a lift that carried the glider rapidly upwards as long as he kept to a course near the coast-line.

The sea breeze may set in as early as nine o'clock in the morning, but, as the heating of the land is cumulative, it reaches its maximum at about three o'clock in the afternoon, and at about this time is at its strongest and freshest. It dies down about sunset, and during the night a light land breeze flows towards the sea. The land breeze is much slighter than the sea breeze, for although the land cools rapidly the sea becomes no warmer than it was, and the difference of temperature between the two is far less than during the day-time.

The alternation of pressure between day and night that gives rise to the sea and land breezes occurs on a very much larger scale between summer and winter, and causes the continental wind systems that reach their greatest development in the monsoons. Continental winds blow outwards during winter and spring, when the land is colder than the surrounding oceans and pressure over it relatively high, and inwards during the summer and autumn, when the land is warmer and pressure over it relatively low.

On an even larger scale the circulation of the atmosphere is conditioned by three permanent belts of low pressure, one over the equator and one encircling

each of the Poles. To what extent these low-pressure areas are due to warmth and moisture and to what extent to the winds themselves it is difficult to determine. However that may be, air rising above these regions creates a low-pressure layer of air near the earth, and a high-pressure layer in the upper levels, and winds flow into them in the lower layers and overflow in the upper layers of the atmosphere. If the earth were stationary it is possible that air currents would rise above the tropics, fall towards the earth in temperate latitudes, and rise again towards the Poles, and winds at sea-level would blow in from north and south towards the equator, and out, northwards and southwards, towards the Poles. Such a simplification, however, has little relation to actuality, and is useful only as illustrating the mechanism of wind, and as emphasizing the fact that winds at sea-level are not the same as winds in the upper atmosphere. Two essential factors have been omitted—the uneven distribution of land and water over the earth's surface, and the rotation of the earth.

Since the earth revolves about its axis once in every twenty-four hours, turning eastward towards the sun, and since, at the equator, its circumference is approximately twenty-five thousand miles, any point on the equator must spin round at the rate of twenty-five thousand miles in twenty-four hours, or rather more

than a thousand miles per hour. Meanwhile the Poles, situated on the earth's axis, remain stationary. Places situated in between turn at a speed determined by the radius of the circle round which they move, in other words by their latitude. For example Quito, almost on the equator, swings round at a speed of approximately $17\frac{1}{3}$ miles per minute, Panama loses a third of a mile and travels at 17 miles per minute, Jamaica has slowed down to $16\frac{1}{4}$, San Francisco to $13\frac{1}{2}$, and New York to $12\frac{3}{4}$, which is about the same speed as that of Rome. London turns at the rate of $10\frac{3}{4}$ miles per minute, Edinburgh at $9\frac{3}{4}$, the North Cape at 7 miles, Spitzbergen at 3, and a point 1 mile from the North Pole at between 6 and 7 miles per day.

This gradual decrease of speed has a turning effect on air moving in any direction over the earth's surface, except at the equator. In the northern hemisphere air that is moving from south to north, that is away from the equator, will pass from a fast-moving area to a slower-moving area. As, according to Newton's first law, any moving body maintains its direction and speed of motion unless some force intervenes to alter it, it will continue the eastward motion due to its revolution with the earth together with the northward motion imparted to it, and will be travelling eastward at a greater speed than the surface of the earth in the neighbourhood into which it has moved.

Consequently its direction, relative to the earth's surface, will be not south to north, but south to east of north, and it will become a south-westerly wind. (It must be remembered that a wind, like a child, takes its name from its source of origin.)

If it is in the southern hemisphere and is moving from south to north *towards* the equator it will pass from a slower-moving area into a faster-moving area, and will have an eastward motion that is slower than that of the neighbourhood into which it has moved and therefore, relative to the surface, it will be travelling from south to west of north, and will become a south-east wind.

Similarly, air that is moving from north to south in the northern hemisphere, towards the equator, will also be turned to the west of south and become a north-easterly wind, and air that is moving from north to south in the southern hemisphere, and therefore away from the equator, will be turned towards the east and will become a north-westerly wind. As a general rule winds moving towards the equator become easterly, and winds moving away from the equator become westerly.

Air moving from east to west will also be deflected from its original course, and will turn away from the equator towards a more slowly moving locality, so becoming a south-easterly wind in the northern hemi-

sphere and a north-easterly wind in the southern hemisphere. Air moving from west to east, in the same direction as the rotation of the earth, will move more swiftly than the ground below, and will therefore turn towards the equator into a locality where its more rapid speed is matched by that of the earth, and will become north-westerly in the northern and south-westerly in the southern hemisphere. It is as though the atmosphere were trying to change its shape into one more in accordance with its speed of motion.

These deflections can be summed up and simplified by saying that winds in the northern hemisphere, whatever their original direction, tend to turn towards the right, and winds in the southern hemisphere tend to turn towards the left. The deflection is greatest near the Poles, and decreases towards the equator. Above the equator itself there is no deflection, and the prevalent winds are from the east, as Aristarchus had surmised. They are not the high winds that he considered an inseparable condition to a revolving world, for on the surface at least the atmosphere almost keeps pace with the earth, lagging only occasionally. Higher in the atmosphere, however, the velocity of the wind increases, and its east-to-west direction is maintained. This was proved after the eruption of Krakatoa, in 1883, when dust-clouds,

at an altitude of about fifty miles, were observed to encircle the earth in twelve days.

The general principles of wind circulation must be applied to the travelling depressions and anti-

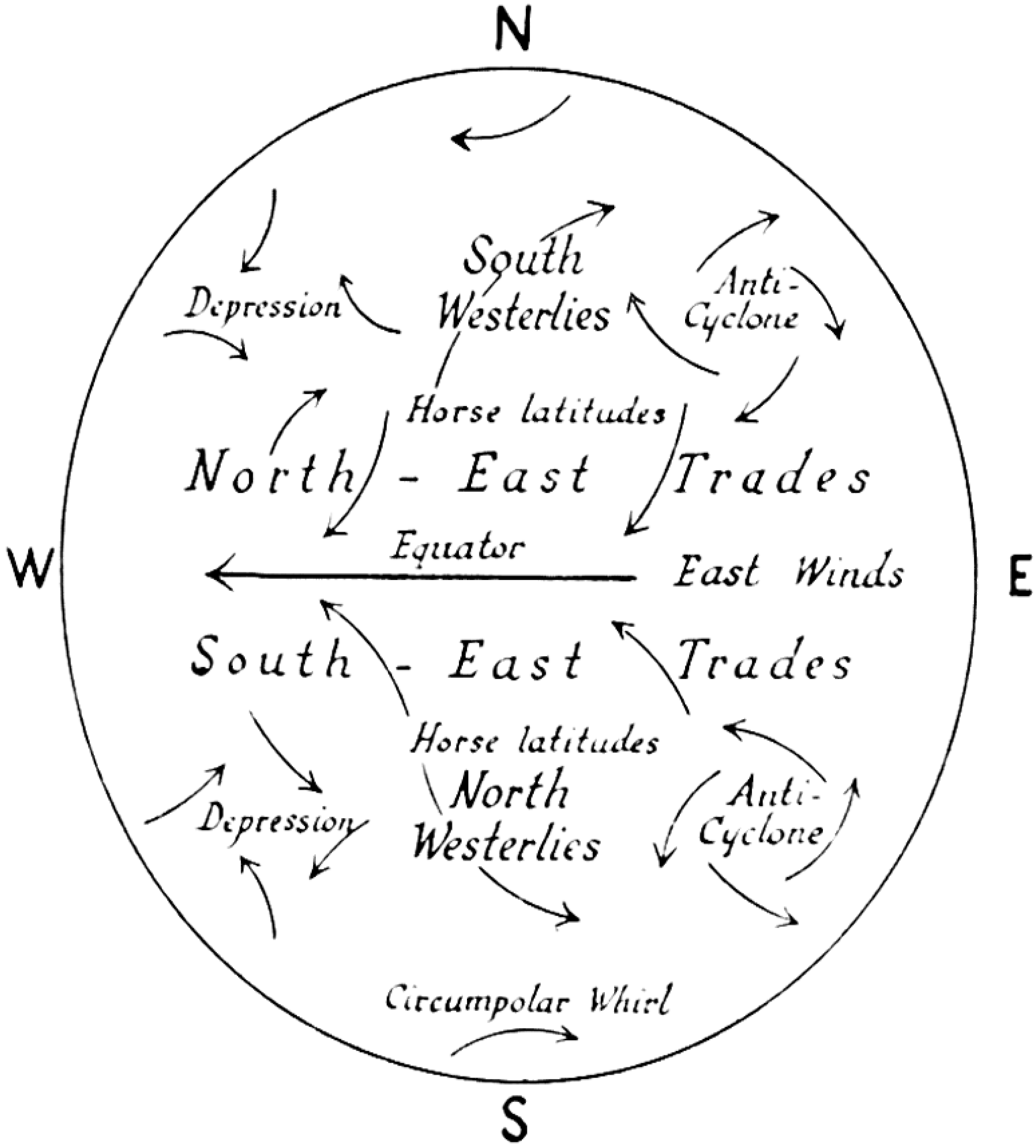


DIAGRAM ILLUSTRATING THE DEFLECTION OF WINDS DUE TO THE ROTATION OF THE EARTH

cyclones that have such a dominating effect on the weather in temperate zones. From what has already been said it can be inferred that near the earth cool air will flow in from all directions towards a region

of low pressure, and out from a region of high pressure, whatever its origin. If depressions and anti-cyclones are pictured for the sake of simplicity—and only temporarily—as circles, air will tend to blow in towards the centre of a low-pressure area and out from the centre of a high-pressure area along radii of the circle. But the spinning of the earth deflects these air currents in both cases. Winds blowing into a low-pressure area turn in the northern hemisphere to the right, blowing anti-clockwise, and in the southern hemisphere to the left, blowing clockwise. Winds blowing out of a high-pressure area are turned in the opposite direction, and blow clockwise in the northern and anti-clockwise in the southern hemisphere.

It will be noticed that in the weather map the arrows indicating the direction of the wind generally point slightly across the isobars at angles varying from about 90 degrees for the light winds at the edge of the system to extremely small angles near the centre, inwards towards a depression and outwards from an anti-cyclone. These directions, if the wind is uninterrupted in its course, are so consistent that if the exact position of the isobars is known the direction of the wind at any place situated within the isobaric system can be calculated. Its speed can also be ascertained, for it is proportional to the pressure gradient, i.e. the difference of pressure measured per-

pendicularly to the isobars. These calculations would be of crucial importance in the planning of a gas attack in the event of war. The only pitfall in the procedure is provided by the configuration of the land. As long as the wind blows over the ocean its path is consistent, but when it blows over the land it immediately becomes subject to other deflecting influences.

In continental wind systems, which are similar on a more permanent scale to the systems of the depression and anti-cyclone, the configuration of the land is a factor that can never be left out of account. Winds tend to follow the course of valleys and to blow around mountain ranges. If they blow over mountain ranges they are not only deflected from their horizontal course but also directed upwards into cooler layers of air. When, as usually happens, clouds are then formed, latent heat is released, the temperature of the atmosphere is raised, and the distribution of pressure is again interfered with. Barometric pressure at sea-level may be increased by the sudden expansion of an air current up aloft. Even comparatively flat land influences the direction of wind, for friction with the surface slows down its speed and in consequence it becomes less amenable to the deflection caused by the rotation of the earth. Friction of one current of air upon another has a similar result, and at the same time tends to warm or cool the air.

Because the processes governing the circulation of continental winds are more numerous than those dictating the circulation over ocean areas, wind systems over large land masses have a more local character and appear more erratic than those over the oceans. For this reason winds in the northern hemisphere, which comprises a much larger land area than the southern hemisphere, are less regular and consistent than winds in the southern hemisphere. If the division, instead of being made by the equator, is made by a line running just above the Tropic of Cancer in the Pacific Ocean, and just below the Tropic of Capricorn in the Indian and Atlantic Oceans, this statement becomes still more applicable.

The influence of the earth's rotation is, however, evident in both hemispheres, and becomes increasingly so, even above continental areas, in the upper layers of the atmosphere where terrestrial influences are less potent and where local winds do not penetrate.

The great winds of the earth, that is to say those that blow most consistently and over the largest areas, owe their impulse to three extensive belts of low pressure. The most permanent is that over the equator, and into it, from the high-pressure belts north and south of it, winds blow from the north-east in the northern and from the south-east in the southern hemisphere. There is also a prevalence of winds that blow from the

south-west in the northern and from the north-west in the southern hemisphere into the low-pressure belts near the Poles.

The girdle of low pressure is more regular in shape and is more constant in south Polar than in north Polar regions owing to the more symmetrical distribution of land and water. It forms a belt that runs roughly along the Antarctic Circle, enclosing a permanent high-pressure area the centre of which is somewhere near the South Pole. Into and round this belt on its northern side north-westerly winds blow with great regularity in what has been called the circumpolar whirl, and on its Polar side blow the anti-cyclonic easterlies. The division between the two varies a little with season and with longitude, but it is so definitely marked that explorers have no difficulty in observing the change in passing from one wind system into the other, and although the observations that have been made are somewhat scanty they are so well in agreement that the regularity of these winds cannot be called in question.

In the north Polar regions, on account of the influence of the large continental land masses, the belt of low pressure is, except over the Atlantic, variable, and anything but circular in shape. During the winter it has two definite foci, one over the north Pacific Ocean, running south of Behring Strait and

over Alaska, and one over the north Atlantic Ocean, which stretches across Davis Strait, west or south-west of Iceland and above the Norwegian Sea. It is as rarely absent from the daily weather map as the clown is absent from a circus. The deep depression over Iceland is not merely a joke originating at the B.B.C. If it is a joke at all nature made it first some millions of years ago when water and land gradually took shape on a seething earth.

These two low-pressure systems are divided by an area of high pressure that practically girdles the earth during the winter, spreading from the Pacific coast across North America, over the Atlantic on the southern side of the low-pressure system, over Europe and Asia, and across the Pacific in two bands that skirt the low-pressure system on either side. In July this high-pressure belt retreats before the onset of the continental low-pressure systems, and occupies a comparatively restricted area over the Pacific and Atlantic Oceans.

The irregularity of these high- and low-pressure systems is so effective in interrupting the circulation of winds near sea-level that they cannot be reduced to a system until more detailed information is available. In this connection it is pleasant to be able to pay a tribute of praise and admiration to M. Ivan Papanin and his three companions, who, with a view

to enlarging this knowledge, established a meteorological station on an ice floe, and with it drifted from the North Pole nearly to the coast of Greenland. The journey—if it may be called a journey—lasted from June 1937 until 23rd February 1938. During this time the explorers, housed in nothing more substantial than tents, and with their instruments accommodated in ice houses, in addition to other scientific research carried on the routine work of a meteorological station and broadcast a daily weather report which appeared regularly in *The Times*. When the darkness of the Arctic night descended upon them they still carried on their work, using little light other than that of the moon and stars, eked out by the pale loveliness of the Aurora. As winter advanced temperature fell to between 30 and 40 degrees below zero, blizzards wrecked their tents and storms churned the icefield into a seething chaos of ice-blocks and fissures. Eventually the floe on which they were encamped was shattered to fragments by a gale, and they were left marooned on a block of ice no more than thirty by fifty yards in area. The rescue of their instruments and the keeping of records in these circumstances was a task of Herculean proportions, but when they were eventually picked up by ice-breakers dispatched to fetch them, men, instruments, and records were intact. The human race is often in these days held up

to ridicule and contempt, and yet time and again it furnishes examples of radiant courage that should surely be enough to confound its detractors.

Winds in the stratosphere and above it have roused much interest and speculation during recent years. Not only are they of the utmost importance in high flying, but they have also a profound and up to the present incalculable influence on weather conditions below. Wind cannot be for ever blowing away from one area at sea-level without returning by some other route. Atmosphere must circulate, as blood circulates, going and returning, and winds that blow north at the earth's surface may return southward in the stratosphere. If this general circulation were perfectly understood it would provide an important clue to pressure distribution. But records are no more easily obtained from the stratosphere than from the North Pole, and although in this region also courage and enterprise have achieved much there are inaccessible heights at which only indirect observations are possible.

The higher cirrus clouds furnish one regular source of information; a rare but alluring source is occasionally provided by mother-of-pearl clouds, floating about fifteen miles above the earth. Higher than this the drift of the smoking trails of meteors can be watched by day at an altitude of between twenty and fifty miles, and by night their luminous trains can be

FRACTONIMBUS CLEARING AFTER RAIN

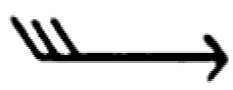
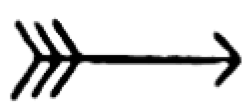
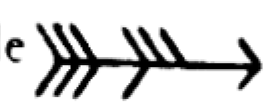
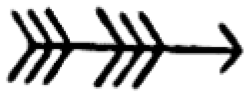
observed at an altitude of between fifty and seventy-five miles. The dust-clouds from Krakatoa floated about fifty miles, and luminous night clouds at between fifty and fifty-four miles, above sea-level. Of regions higher than the paths of the highest meteors no visual observation is possible.

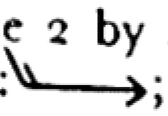
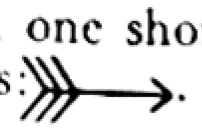
From the records thus variously gathered, and by mathematical calculations based on the dynamics of the atmosphere, theories have been propounded to account for the general circulation of the atmosphere about the earth. It seems probable that a strong east wind rises above the equatorial calms, eventually overflowing as a west wind (south-west in the northern, north-west in the southern hemisphere), and falling to earth-level in south temperate and north temperate regions. Exactly how it reaches the Poles is doubtful, and still more doubtful is the path of its return journey, though it is thought that the travelling depressions so frequent in temperate latitudes must have some part in it. It also seems probable that great air currents of this nature tend to form enormous billows, which, as they rise, allow warm air to flow in beneath, and as they fall bring blizzards and dry weather; at the same time these billows must mix and intermix with the lower air as waves turn and overturn. Wind paths in three-dimensional space must be exceedingly intricate, and any account of them must be largely hypothetical.

One remarkable fact about winds in the upper atmosphere that has been definitely established is the great speeds that they attain, speeds that would bring universal disaster if they occurred near the earth. Cirrus clouds have frequently been observed to travel at speeds varying between 100 and 225 miles per hour, mother-of-pearl clouds at 170 miles per hour, and luminous night clouds at anything between 66 and 660 miles per hour, whilst the trails of meteors reveal the presence of similar high winds at still greater heights.

A wind of 100 miles per hour gains in significance when compared with the normal speed of winds near the earth's surface. In the year 1805 Admiral Sir Francis Beaufort compiled a wind scale for the guidance of sailors, giving the approximate wind speed with its appropriate sailing directions. This scale was so apt that, with amplifications made by the Royal Meteorological Society, it is still in use, and it gives better than any more original description a clear idea of wind speeds at ground-level. For this reason, and because it is indispensable to all amateur meteorologists, it is given below. It will be noticed that a wind blowing at thirty-five miles per hour is already a moderate gale, and that with a hurricane above seventy-five miles per hour the limit of description is reached. Perhaps it is as well that we do not know what word the admiral would have applied to a wind of six hundred miles per hour.

THE BEAUFORT WIND SCALE

Beaufort Number	*Wind*	*Symbol*	*Speed m.p.h.*	*Commonly observed effects of corresponding winds*
0	Calm	⊙	0	Calm; smoke rises vertically.
1	Light air		2	Direction of wind shown by smoke drift but not by wind-vanes.
2	Light breeze		5	Wind felt on face; leaves rustle; ordinary vane moved by wind.
3	Gentle breeze		10	Leaves and small twigs in constant motion; wind extends light flag.
4	Moderate breeze		15	Raises dust and loose paper; small branches are moved.
5	Fresh breeze		21	Small trees in leaf begin to sway; crested wavelets form on inland waters.
6	Strong breeze		27	Large branches in motion; whistling heard in telegraph wires; umbrellas used with difficulty.
7	Moderate gale		35	Whole trees in motion; inconvenience felt when walking against wind.
8	Fresh gale		42	Breaks twigs off trees; generally impedes progress.
9	Strong gale		50	Slight structural damage occurs (chimney pots and slates removed).
10	Whole gale		59	Seldom experienced inland; trees uprooted; considerable structural damage occurs.
11	Storm		68	Very rarely experienced; accompanied by widespread damage.
12	Hurricane		above 75	——

Note: In some weather maps force 1 is indicated by a short barb: ; force 2 by a long barb: ; force 3 by one long barb and one short one: ; and so on; force 12 being indicated by six long barbs: .

IV

THE WINDS

Having gained some idea of the mechanism of wind and the manner of its coming and going about the earth we can turn with more understanding to the familiar winds that blow over the earth's surface with sufficient regularity to earn for themselves recognition and names.

Near the equator there are few winds of any kind. Hurricanes and tornadoes rarely approach nearer than ten degrees, and temperature conditions are so uniform that the average variation between day and night is greater than that between season and season. It is a belt of calms. Winds flowing towards it lose

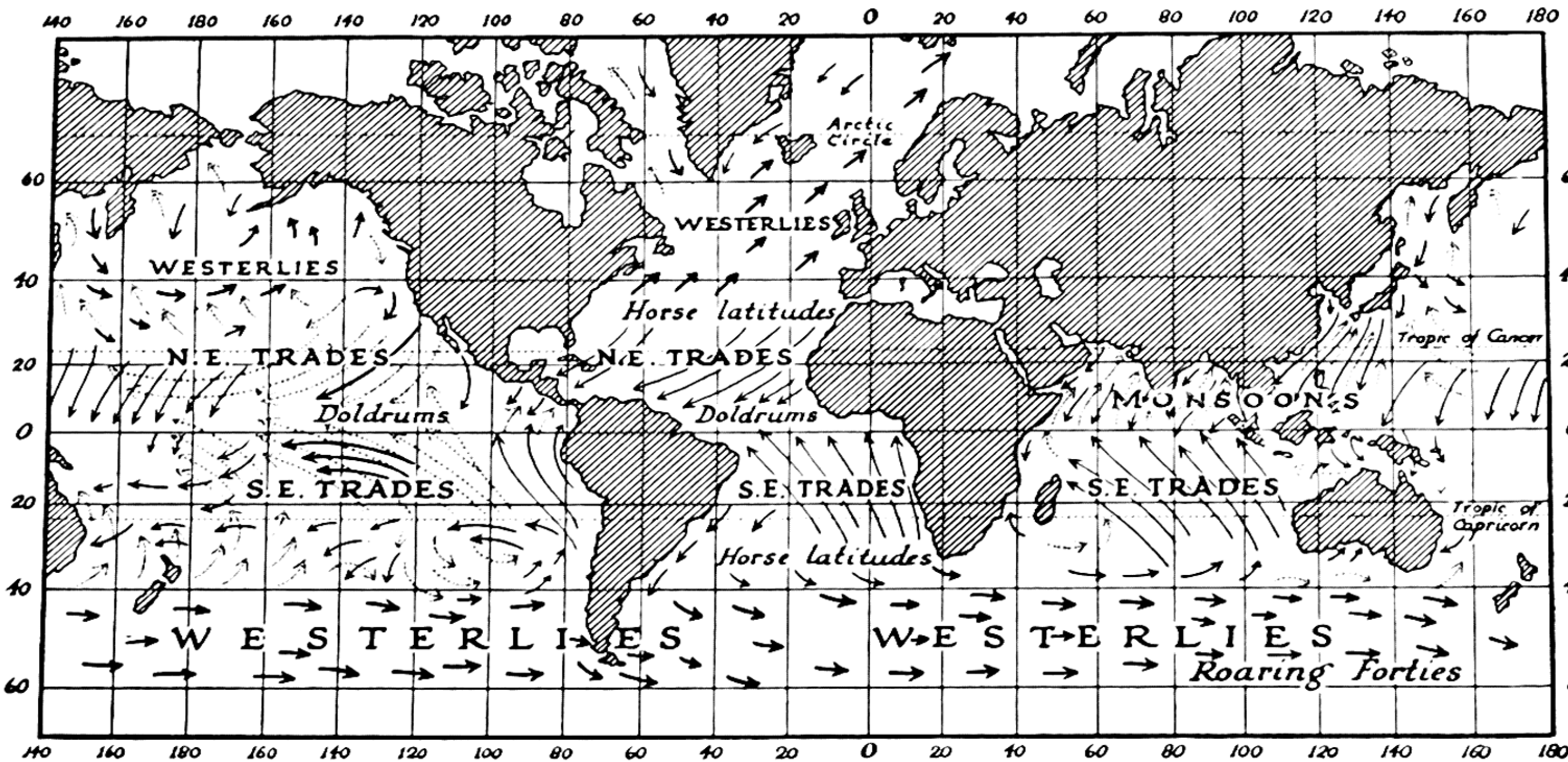


DIAGRAM SHOWING THE REGIONS OVER WHICH THE GREAT WINDS BLOW

(Where there is a marked change of direction between January and July the direction for July is shown by dotted arrows. The longer arrows indicate very steady winds, the broader arrows very strong winds)

their vitality and forsake the earth for loftier regions, and such winds as blow are variable and uncertain. No doubt it was the reaction of sailors to these conditions that gave the word 'Doldrums' as sinister a meaning in the Victorian nursery as the unfortunate little black dog. The Victorian Nannie would probably have received something of a shock, however, if a change of temper had been announced in the terms, 'Well, Nurse, we're well in the Trades again now.'

Trade winds are the winds beloved of sailors, for they are the most constant of all that blow, and, however unpleasant their effect is apt to be on land, at sea they bring with them fair weather, clear skies, and invigorating air. Although it was certainly the Trades that carried the larger part of the world's trade until steam superseded sail, that is not the origin of their name. Trade is used in its now obsolete meaning of 'course', a name they earned from their constancy of direction, which is north-east in the northern, south-east in the southern hemisphere.

They blow into the low-pressure belt that hovers over the equator from the high-pressure belts north and south of it, with the easterly turn imparted to them by the spinning of the earth. The Doldrums belt, owing to the land and water distribution, is slightly north of the equator except during the summer of the

southern hemisphere, and the influence of the Trades is therefore felt between latitudes 3 and 35 degrees north, and from the equator to latitude 28 degrees south. They are at their steadiest over the immense ocean areas in the Pacific and Atlantic, and over the southern Indian Ocean; and they blow more intermittently over the land from Mexico to Brazil, from the Sahara to South Africa, and over Australia. Over the great land masses of Asia other winds are dominant.

Constant though they are it is only a relative constancy and they are not allowed to blow without interruption. In the first place they swing north and south with the seasons, keeping pace with summer in either hemisphere. In the northern winter they encroach on the Doldrums from the north, and in the eastern Pacific sometimes blow right over the equator. In the southern winter the Doldrums move north and in the same regions the Trades blow over the equator from the south. Tracts like the Sudan and the Campos of Brazil owe their characteristic climate to the fact that they are sometimes in the Doldrums belt and sometimes in the trade-wind belt; the warm moist climate of the Doldrums alternates with the dry climate of the Trades, and vegetation that springs up luxuriantly under the influence of the former withers away under the influence of the latter.

At the other extremities Spain, Italy, and Syria in the north, and Cape Town in the south, are in the Trade-wind zone in summer and in the Anti-Trade zone in winter, and the hot dry climate due to the Trades alternates with the cool unsettled climate characteristic of temperate latitudes. In latitudes where the Trades blow all the year round they have created the great desert regions, which in the northern hemisphere extend from the Sahara across Arabia to the Gobi Desert. In the southern hemisphere the desert zone is mainly covered by the ocean, but it includes the Kalahari Desert in South Africa, the great drought areas of Australia, and the shingle wastes of Patagonia.

In addition to the march of the seasons Trade-winds suffer interference from continental inflow and outflow, and from diurnal land and sea breezes. Land masses, wherever they are, tend to establish wind systems of their own, and although near the equator seasonal variations are slight diurnal differences are often considerable. Local sea breezes are of great climatic importance, and may make all the difference as to whether a locality is habitable or not.

The greatest wind system established by continental inflow and outflow is that of the monsoons. They cause more than an interruption to the Trades,

for where the typical monsoons develop they reign supreme.

Inflowing and outflowing continental winds depend for their extreme development on two conditions, first on a considerable seasonal variation in temperature, and secondly on land configuration favourable to the augmentation of their force. Where a continent consists of a low plain, or even of a plateau with a narrow coastal strip, there is nothing to increase the original impulse of the wind; but where the land slopes gradually upwards towards a central mass the impulse is cumulative, the force of the wind increases as it advances, and its acquired velocity may carry it over wide areas far beyond the district where the conditions originally responsible for it obtain.

Within about 15 degrees north and south of the equator seasonal variations of temperature are slight. The same is true in a different sense of the land masses lying within the temperate zone. They are never really hot enough, and the equatorial regions are never really cold enough, to develop the typical monsoon. Between these zones, in Australia, in West and South Africa, and in the southern part of the United States of America temperature contrasts are considerable and all these areas at times come under the influence of the monsoons, which interrupt or

modify the Trade-winds to a greater or lesser extent. The true monsoon areas, however, are southern and eastern Asia.

Both India and southern China rise by gradual stages to the huge mountain mass of the Himalayas, which is from three to five miles high, and divides the two countries so effectively that not even the monsoons surmount the barrier, for they are essentially terrestrial winds, having their origin on the earth's surface. Although both India and China are monsoon regions they have their separate and independent systems.

In India in the winter temperature gradients rise steadily from north to south, and the isotherms run almost parallel with the lines of latitude; consequently the pressure gradients descend like a flight of steps, down which the winds fall, gaining impetus as they proceed. They acquire a westward direction from the earth's rotation, and so join forces with the Trades, blowing from a north-easterly quarter from October to March or April.

In China conditions are similar. The isotherm of 32 degrees Fahrenheit crosses Asia between the Yangtze and the Hwang Ho, whilst the winter temperature of southern China averages between fifty and sixty degrees. The monsoons blow from about October to April, north-west in the north, and north and north-

east in the south over the China Seas, where, as in the Indian Ocean, they identify themselves with the Trades and blow onwards until they reach the Doldrums belt.

In summer the conditions are reversed, the temperature gradients rise from south to north, and both in southern China and in India the monsoons are dominant in the opposite direction. In early summer the hottest area in India is over the Deccan, but by midsummer it has moved farther north, and forms a vast low-pressure system over the Indus lowlands and Baluchistan. The wind blows in towards the land, beginning over the Arabian sea about April as a west or north-west wind, gradually becoming south-west as summer advances, and veering again to north-west with the approach of autumn. During the same period the monsoons blow over the Bay of Bengal as south and south-easterly winds. As soon as they reach the land itself their direction is diverted, both by the influence of the area of lowest pressure, and by the shapes of the mountains and valleys. Between the Himalayas and the Deccan they follow the path of least resistance, blowing up the Indus as a south wind, and along the Ganges valley as a south-east and east wind, until they eventually lose both force and direction amongst the great mountain ranges. Thus they offer a striking example of the three major

influences dominating wind circulation, for they originate in the unequal heating of land and water, are deflected by the rotation of the earth, and are diverted by the configuration of the land.

The summer monsoons are more violent than the winter monsoons because, blowing as they do from sea to land, they pick up a large quantity of water vapour as they pass over the water. When the wind is directed upwards into cooler regions by the rising ground this is precipitated into water-drops, and the large amount of latent heat released provides additional driving power. The winter monsoons, blowing first over the land, do not pick up much water vapour in the earlier part of their course, and so gain little impetus from the release of latent heat.

At all times, and particularly during the period when they are changing their direction, monsoons are liable to interruption from violent cyclonic storms, originating principally in the opposition of contrary air currents. They are particularly frequent during the warm months of August, September, and October, and in the China Seas, where they are known as typhoons. As many as a hundred typhoons may blow during the course of a year, and as they frequently reach hurricane force (No. 12 on the Beaufort Scale) they do incalculable damage to shipping and property. Japan, in particular suffers serious loss every year

from typhoons, disasters against which the ingenuity of that resourceful nation is unavailing.

North and south of the Trade-winds, approximately between latitudes 40 and 60 degrees, is the region over which the great eastward current sets in, blowing under the influence of the earth's rotation towards the low-pressure areas that ring the Poles. These are the 'brave west winds' or 'the stormy westerlies' that blow as south-west winds in the northern and as north-west winds in the southern hemisphere.

Over the British Isles the prevailing winds are westerly, not so much because they lie in the track of the great westerlies, but because the travelling depressions that form in the neighbourhood of Iceland and over the Atlantic usually follow a course either above or across the north of Scotland towards Scandinavia. The greater part of the British Isles is therefore affected by the winds of the southern sector, which, blowing anti-clockwise round the centre of low pressure, veer from south-west to north-west according to the position of the depression.

In passing over the Atlantic these relatively warm air currents pick up a great deal of moisture which they let fall as rain as they move across the country from east to west. They are cloud-bearing winds, nurses of velvet lawns and green hedges, of violets and

primroses, and all the sweet things that owe their loveliness to rain rather than to sunshine. A strong contrast are the dry east winds that, frequently in early spring, interrupt them, blowing from the high-pressure areas over Europe. The latter are lazy winds and blow intermittently, giving place in winter to frequent fog. When they have enough energy to disperse it, however, they bring clear skies, wide horizons, and spacious nights, with the night frosts that wither the early blossom.

The Westerlies are steadier aloft than at sea-level, where they are much interfered with by continental wind systems. In the northern hemisphere their course is more erratic than in the southern hemisphere, where they blow with considerable dependability over large areas of ocean, and near the latitude of forty degrees south with such force that this belt has gained the name of the Roaring Forties. Around Cape Horn, laden with sleet and snow, they seem to blow with peculiar malice.

The Trade-winds, the Westerlies, and the monsoons are the great winds of the earth. They blow over large areas and have a dominating influence over climate. In addition to these great winds there are local winds due to local geographical conditions, winds that have a marked effect on the climate in the districts where they blow, but a very local effect.

They are like town councillors, influential in their own small sphere, but of little account in world affairs.

Of these provincial winds one of the best-known is the *mistral*, which blows between the mouth of the Ebro and the Gulf of Genoa, changing in an hour the balmy air of the Mediterranean littoral to teeth-chattering cold. It blows down the Rhone valley from the high-pressure areas that form in winter above the chilly heights of the Central Plateau of France, towards the low-pressure area that forms over the warm waters of the Golfe du Lion. If, on this central plateau, there has been a snowfall, still further chilling the surrounding air, or if a depression is centred over the Golfe, its force increases to extreme violence. It is most prevalent in Provence and Languedoc, where it blows on an average on one day out of every two, bringing with it intense dryness and brilliant sunshine. But it is a bitter, deceitful wind, and those who have sought the French Riviera for the mildness of its climate had better keep safe indoors until its bland malice is spent.

A similar wind is known in Italy as the *tramontana*, and over the Adriatic, blowing most frequently in Istria and Dalmatia, as the *bora*. It originates above the central European plain, and is felt as far east as the Black Sea. Istambul itself is not free from its freez-

ing influence, and in the spring, in spite of its latitude, may be as cold as Scotland.

A still more baneful wind is the *buran*, or *purga*, which blows across the interior of Russia and Siberia, and over the Gobi Desert, carrying in its teeth snow or ice or stinging sand, a deadly wind that every year takes its toll of life.

A well-known warm wind is the *Föhn* (or *Foen*), which, although its name originates in the European Alps, occurs in most mountainous districts, notably in Scandinavia, Greenland, in the Rocky Mountains, and in the south Polar regions, and to a lesser degree on the eastern side of the mountains on the west coast of Scotland. It is occasioned by the heating of mountain valleys, which gives rise to areas of low pressure, and so causes a rapid indraught of air from the heights. On the far side of the mountains the air has risen, but the process of dynamic cooling has been reduced by the formation of clouds. As it falls into the heated valley, rolling under the rising air, its descent is so rapid that it is compressed, and so effectively warmed and dried by dynamic heating that it blows as a warm dry wind, and causes a rapid rise in temperature, even in Polar regions. In the Rockies it is known as the 'chinook', and the Indians say of it that it 'licks up the snow'.

'Sirocco' is the name given to two distinct types of

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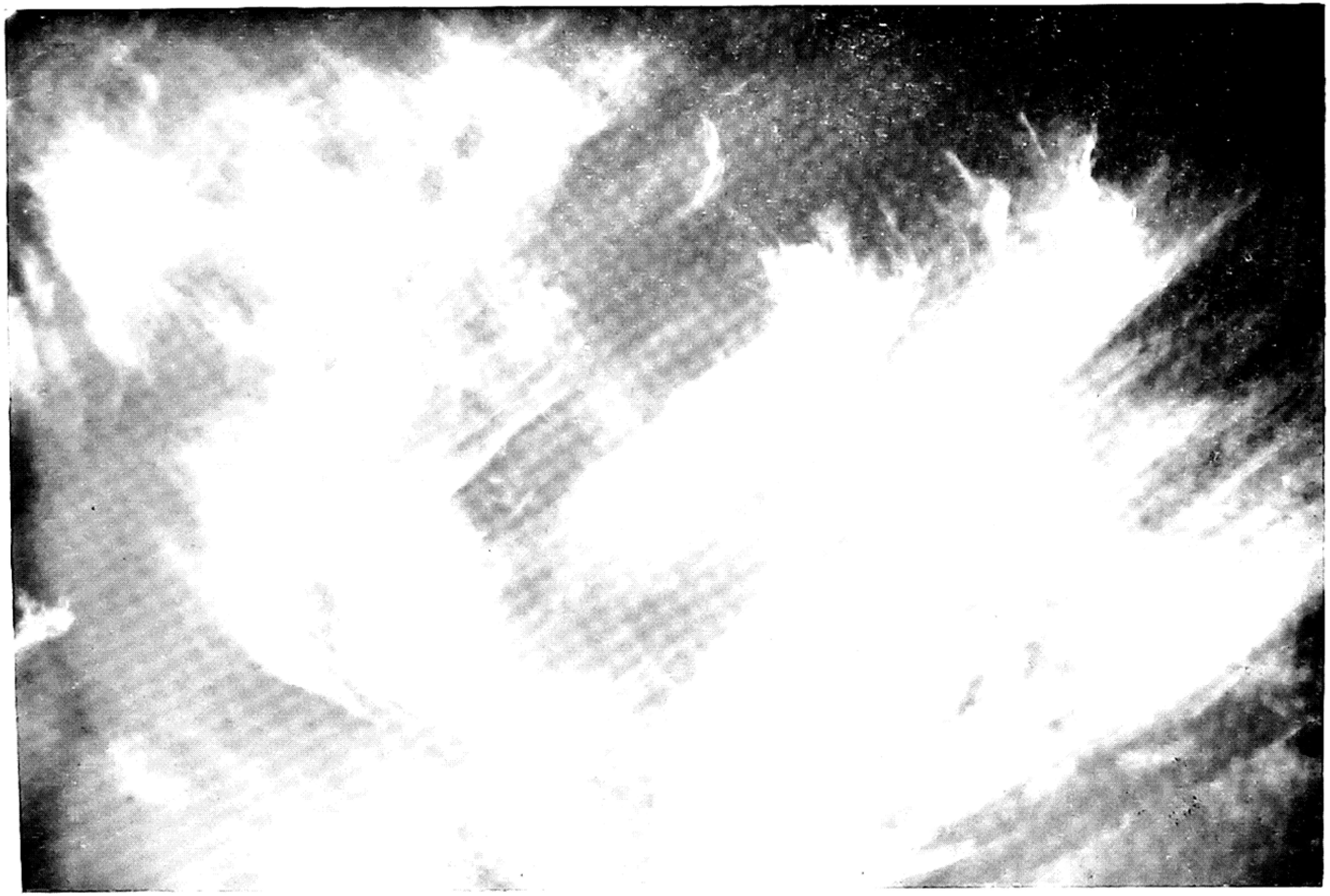


CIRRUS—TUFTED WISPS

wind, but it is used most frequently in connection with the dust-laden winds that originate in deserts. As such it blows in various directions according to the situation of the desert from whence it comes, and is known in different countries by different names: as *scirocco* in Sicily, southern Italy, and Greece, where it blows as a southerly wind from the Libyan desert, and as a south-westerly wind from the Sahara, and, picking up moisture in the Mediterranean, becomes moist and warm; as the *leveche* in Spain, where, blowing also from the Sahara, it reaches the coastal regions of the south-west; as the *leste* in Madeira, where it blows from the continent as an east wind; in Senegal as the *harmattan*; and in Algeria, Syria, and Arabia as *simoom*. In Egypt it takes its name from the Arabic word for fifty, *khamsin*, because it blows on an average for fifty days during the spring months. Similar winds that blow in South Australia from the central desert region are familiarly known as 'brickfielders'.

The name 'sirocco' is also given to the wind that is prevalent during the winter rainy season on the Mediterranean littoral. In this case its direction is usually south or south-east, for it is the inblowing wind, with the right turn characteristic of the northern hemisphere, that occurs on the eastern side of a depression.

Before leaving the subject of local winds both the tropical cyclone and the tornado might be mentioned,

although they are best described not as winds but as circular storms, and are local only in the sense that conditions necessary to their formation are peculiar to certain latitudes.

The tropical cyclone occurs between latitudes 6 degrees north and 20 degrees north, and 6 degrees south and 20 degrees south. It is of the same nature as a depression, but of smaller extent, the isobars are more nearly circular, the pressure gradient much steeper, and the winds therefore of much greater velocity. The area covered by the closed isobars of a cyclone is generally considerably less than three hundred miles, and from circumference to centre there is frequently a fall of sixty millibars. In the centre of a cyclone, the eye of the storm as it is called, the air is calm and clear, but the sea is turbulent, and this is actually the most dangerous quarter for navigation. Around the centre the wind blows with hurricane force, often exceeding 100 miles an hour; exact data are therefore scarce, for measuring instruments do not often survive the violence of the storm.

The tornado is peculiar to the southern states of America, and occurs most frequently in the Mississippi valley during hot weather. Its structure is a very low-pressure area, high above the earth, towards which an air current ascends with such rapidity that it takes on a swift spiral motion, within which is created a

funnel of exceedingly low pressure that sucks up dust and débris from the ground into a whirling cloud. It advances at the rate of from twenty to forty miles an hour, and in its narrow path it carries destruction.

Since the days of Odysseus, who carried them with him conveniently wrapped up in an ox-hide, the winds have multiplied exceedingly—or rather our knowledge of them has increased and we are familiar with the numerous offspring of the original sackful, with their origins, their characters, their habits, and their haunts. And yet it must be evident that in forecasting a wind in a particular neighbourhood during any definite period a considerable amount of uncertainty is involved, perhaps a little less than in prophesying the winner of the Derby, but still a good deal. In estimating the chances of a horse the only guide is its behaviour during the limited period of its racing career, but our knowledge of winds extends over some hundreds of years, and statistics therefore provide a safer guide than they do in horse-racing. In meteorology there is much to be said for fitting theories to facts, and records of the speed and direction of winds are of fundamental importance. Methods of observation in the higher layers of the atmosphere have already been described; for observation nearer the ground the instruments used are the wind-vane and the anemometer.

In choosing a position for them it is important to realize how very easily air currents are deflected. If the instruments are placed near any obstruction to the free flow of air in the neighbourhood the eddies formed will render the records valueless. The top of a mast thirty-three feet high, well removed from trees and buildings, is recommended, and a standard wind-vane such as is used at meteorological stations.

Anemometers are of two kinds, those measuring speed directly, and those measuring the pressure and deducing therefrom the speed. There is a definite relationship between speed and pressure but one difficult to calculate, for pressure varies both with the density of air and with its water content. The relationship is nevertheless sufficiently constant to give information on both points.

Pressure anemometers, like barometers, can be divided into two classes, those that record pressure against a plate connected with a spring, and those that record pressure against a tube of liquid. The plate method gives reasonable accuracy in a steady wind, but is unreliable in a gusty wind, for two successive gusts may record a pressure far greater than that actually attained by either, and the velocity of the wind deduced from it will be far in excess of the real speed. The tube type is more convenient, but it must be corrected for altitude, and also for extreme

variations of barometric pressure. Both plate and tube type require a wind-vane to keep them directed into the wind.

The type of anemometer that is most popular and on the whole most satisfactory is the cup type, now a familiar feature of the country landscape. It consists of a horizontally rotating metal cross with a hollow cup attached to the end of each arm. The wind blowing into the cups on one side imparts a greater velocity than is lost as it flows round them on the other, consequently they revolve, and the speed of the wind can be calculated from the rate of revolution. The ratio varies a little according to the length of the arms and the size of the cups, and there is a general tendency to overrate the speed. As a general rule five hundred turns of the cups corresponds to about a mile of wind, but each instrument requires careful testing if an accurate result is to be obtained.

A factor to be reckoned with in considering the records of all these instruments is inertia. It takes a stronger gust to set the instrument in motion than to keep it moving, and it will continue to revolve for some time after the force of the wind that moved it has abated. Consequently the first light breeze goes unrecorded, and the last breath of a dying wind still makes its record after the wind itself has passed on.

V

RAIN, HAIL, AND SNOW

Up to this point weather has been pictured as an elemental dance executed about the earth and up to the fringe of space by the molecules that compose the atmosphere. The picture is an inspiring one, for it answers to some vague human need of disciplined freedom, but it is incomplete. There is also rain.

Apart from some passing references to the moisture content of the air, and to the driving power provided by latent heat released in the formation of water-drops, rain has been ignored, but it cannot be conveniently ignored for long, except perhaps in the Sahara.

Although it is usual to talk of the moisture content of the air, vapour is contained in the air only in the sense that an ingredient is contained in a mixture and is independent of the other ingredients, which in this case are gases. Water will evaporate into a vacuum at a suitable temperature, for it is not soaked up by the air like water into a sponge. It rises into it by means of energy derived from radiation, from the air, or from the water itself. The amount of water vapour that a certain amount of air is able to contain is not dependent on the proportion of its gases but on their temperature and on the volume they occupy.

Warm air is capable of accommodating a larger quantity than cold air, and as, in the free atmosphere, a pound of dry air at low pressure occupies more room than the same amount at high pressure there is also more room for water vapour. At average pressure (1,000 mb.) a pound of air can hold one-sixteenth of an ounce of water vapour at freezing point; one-eighth of an ounce at 50 degrees F.; one-quarter of an ounce at 70 degrees F.; and one ounce at 110 degrees F. In the warm atmosphere of the tropics the water content reaches a little over two ounces to the pound.

All moist surfaces, not only seas and streams but also damp earth and vegetation, evaporate into the

air as long as it holds less than its full amount of water vapour. When this amount is reached it is said to be saturated. When saturated air loses some of its heat it cannot hold so much water vapour, and some of it condenses into droplets. It is then said to be at dewpoint. In certain circumstances air may carry more than its full amount of water vapour, and is then said to be super-saturated, a condition that is possible owing to the peculiar mechanism of condensation.

The formation of water-drops requires, it seems, a little encouragement, and in the atmosphere this encouragement is provided by particles which assist condensation of water vapour and so form a very small drop. Free air always carries minute, and for the most part invisible, fragments of various material substances that are conveniently summed up in the comprehensive word dust. It is indeed a comprehensive word, for it includes a dozen or more types of particle, of which the most important are the following:

1. Mineral dust from slowly disintegrating rocks.

2. Vegetable dust from decomposing vegetable matter.

3. Pollen from flowers and trees.

4. Spores and bacteria.

5. Soot and mineral ash.

6. Salt particles from sea spray.

7. Particles formed by the union of water vapour with the gases of ammonia, oxides of nitrogen, oxides of sulphur, etc., which are known as hygroscopic particles.

8. Volcanic ash.

9. Meteoric dust, several tons of which are deposited on the earth every year by the millions of small meteorites that fall into the earth's atmosphere from space.

If all dust is removed from a sample of air it can become super-saturated; if the super-saturation is increased fourfold, water-droplets will form on charged atomic particles, that is to say on atoms that have lost one or more of their outer electrons, and so have become positively charged, or ionized; or even on the negatively charged electrons themselves. In dust-free air containing no atomic particles water-droplets do form eventually, but with extreme reluctance, and eight- or nine-fold super-saturation is necessary before the process begins.

The formation of a cloud of water-droplets can be observed in the laboratory by introducing into a flask containing saturated dust-free air a very small quantity of smoke. The formation of droplets on atomic particles can be observed in an apparatus known as the Wilson Cloud Chamber, which was constructed

some years ago by Professor C. T. R. Wilson for the purpose of investigating the disintegration of atoms. It consists of a vessel filled with super-saturated and dust-free air, which by means of a piston can be made to expand suddenly, and so cooled. As there are no dust particles present on which the water vapour can condense it makes use of charged atomic particles for the purpose, and reveals their presence in a trail of droplets.

In the atmosphere warm air rising from the earth expands and cools. If it contains an appreciable quantity of water vapour it will eventually, as the rising and expansion continue, reach a point at which its water content is greater than at its reduced temperature it can support. The excess will be attracted towards whatever particles are at hand, and condense into water-drops and form a cloud.

A cloud, however, is not rain. The majority of clouds are not even potential rain, for the process that makes them, being reversed, will unmake them, and when they sink and become warm again they will evaporate. High clouds are not rain clouds, and although they sometimes foretell rain by showing that there is a good deal of moisture in the air the rain itself will fall from clouds at a lower level.

It is estimated that ordinary air contains nearly forty thousand dust particles per cubic inch; the drop-

the size of the surface presented to the resistance of the air. If the mass of a drop were to increase at the same rate as its surface dimension it might remain suspended indefinitely, but it does not. Its mass increases as the cube of the radius and its surface dimension increases as the square of the radius, and therefore the force of gravity exerted upon it increases more rapidly than its resistance to the air.

It seems probable that raindrops, or droplets, begin their existence in the upper part of a cloud, where the rising air has been partly filtered of condensation nuclei by the droplets already formed in the lower portion. If the condensation nuclei were less numerous, the droplets formed on them would be less numerous, and therefore even in their initial stages they would be larger.

Even so, and buoyed up as they are by rising air currents, other processes must be at work to increase their growth. Rain-making is still something of a mystery, but there are probably several agencies concerned in it, and possibly all of them, to a greater or lesser extent, have some part in it. Wind, or what is more pompously called mechanical turbulence, no doubt blows the droplets together. The more rapid cooling of the upper portion of a cloud, causing it to contract and sink, would provide opportunities for further growth. The electrical attraction of drop-

lets formed on positively charged nuclei for droplets formed on negatively charged nuclei would cause them to unite when they were near enough together. It is just possible that agitation of the air produced by sound waves might have a similar result. It is not entirely superstition that connects gun-fire with rain. Sound-waves travel in air in forward pulses, and the disturbance created by explosions of great magnitude, such as a bombardment or an eruption, might cause droplets to run into each other and coalesce. In one way or another the original small cloud droplets must grow large enough to fall through the air current in which they are formed if there is to be any rain at all.

Before going on to consider the different types of rain it might be well to go back a little and explain why some winds, notably the Trades, are dry winds, and others, like the Westerlies, are wet. A current of air blowing from a cool to a relatively warm quarter becomes a dry wind because the amount of moisture that it picks up in its latitude of origin is less than it is able to carry when its temperature rises in warmer latitudes, and is therefore unlikely to precipitate into rain. A current of air blowing from a warm into a relatively cool neighbourhood becomes a wet wind because the amount of moisture that it picks up in lower latitudes is more than it can contain when its

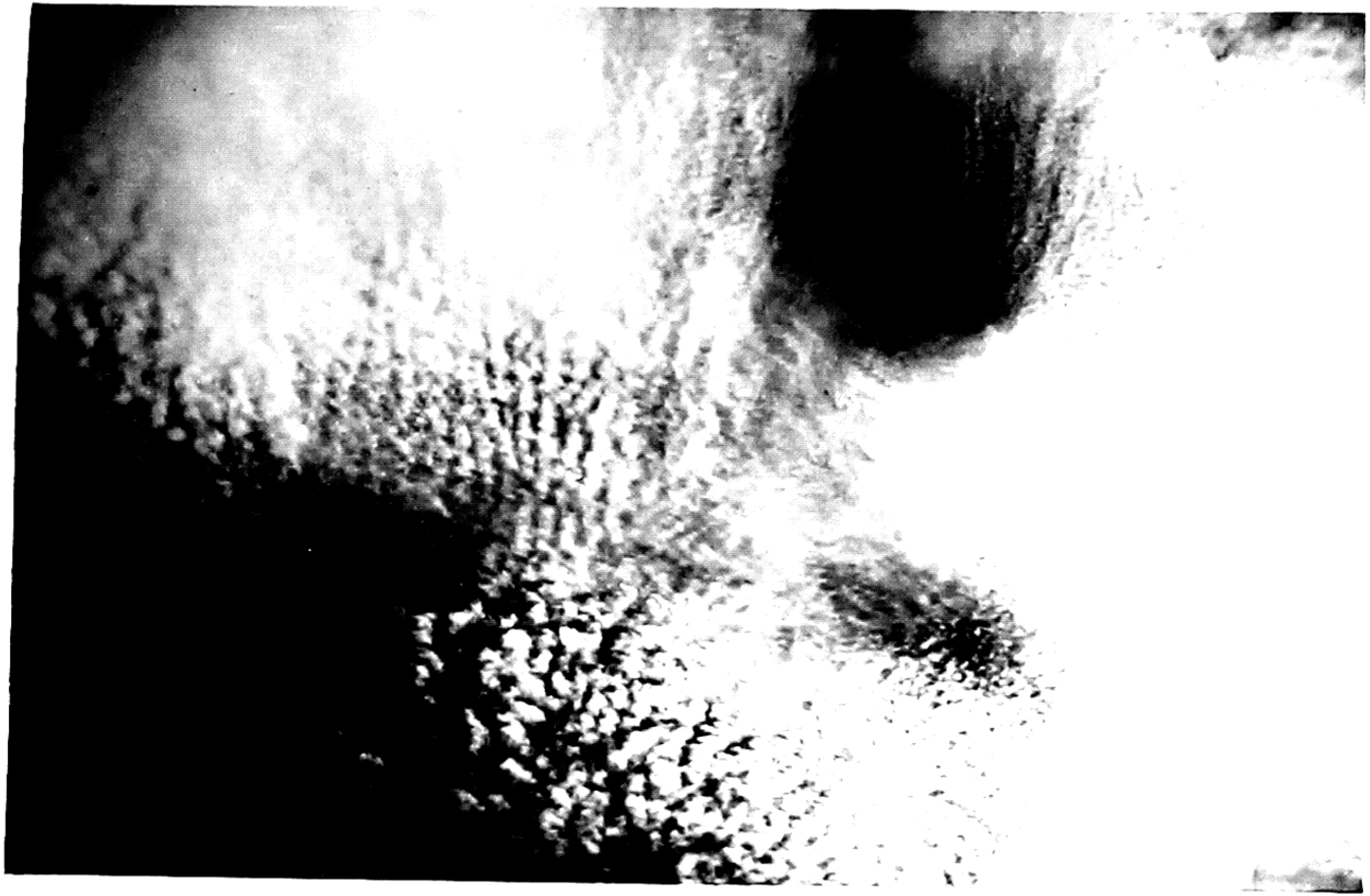
temperature falls as it reaches higher latitudes. If it has blown over a large area of ocean it will carry a large amount of water vapour, and this, at the first opportunity, will turn into rain.

The Trade winds, blowing from temperate latitudes into the tropics, are dry, and the Westerlies, although they also originate in temperate latitudes, are wet, because they blow in the opposite direction towards the Poles. In Polar regions rainfall, or rather precipitation in the form of snow, is small because the temperature of the air is always low, and its water-vapour content is exceedingly small. The impression, a very general one, that snow falls in great abundance, is due to the fact that once it has fallen in districts where the temperature is rarely above freezing it is very slow to disappear. Unlike rain it cannot soak into the earth, but remains where it falls, to be blown about as if it formed another snowstorm. Rainfall increases with height up to about seven thousand feet but decreases rapidly after it has reached its maximum, owing to the lack of moisture in the air. At two and a half miles high the thermometer is normally at freezing-point, where the maximum water-vapour content, even at average pressure, is only one-sixteenth of an ounce to the pound, and at seven miles the water-vapour content has fallen to 0·01 per cent.

However moist a wind may be it does not precipitate into rain merely by blowing north or south. Whilst it continues to blow horizontally it tends to keep its original temperature and so retain in vapour form its load of moisture. Winds do not mingle with each other very readily, and a warm and a cold current may blow alongside each other, like contrary lines of traffic, without appreciably altering the temperature of either. When currents of different temperatures meet they usually blow over or under each other, and the change of temperature then involved is due to expansion or contraction, and only to a small extent to mixing.

This is one of the ways in which moist air may be cooled. There are various other ways, and it is the manner of cooling that determines the type of precipitation that results.

Dew is formed by the cooling of a thin layer of moist air lying on the earth's surface. The rapid loss of heat by radiation from the earth after sunset, especially on clear nights, has already been described, and the fact that water retains heat for a longer period than solid substances has also been mentioned. Water vapour has the same characteristic as water; the moist air close to the earth cools much more slowly than the ground and in order to readjust the balance radiates its own heat back to the earth, becoming cooler in



CIRROCUMULUS. THE TRUE TYPE OF THIS CLOUD (CIRRUS THREADS STILL SHOWING IN PLACES)

the process. In time it reaches dewpoint, and the excess moisture is deposited in the form of drops on the surfaces that have cooled most rapidly. Condensation nuclei in this case are not necessary, because the air is already in contact with the ground. If the cooler surfaces have already reached freezing-point the precipitation will be in the form of minute ice crystals, which will form hoar frost.

It is not difficult to predict from observable conditions a heavy or a light dew, nor is it difficult to see why the countryman is right in saying that a black frost is colder than a white frost. For a heavy dew a warm day is required and a clear night. If the night is cloudy dew is rarely very abundant. Nor will there be much dew if there is sufficient wind to keep the air in contact with the earth in constant motion, and so prevent its excessive cooling.

Lack of hoar frost during freezing weather shows that the air has been too cold during the day for moisture to evaporate into it, and at night both ground and air are so cold that the difference of temperature is negligible. Rime is formed only in fog, and not by direct precipitation on to cold surfaces, but by the droplets that form the fog itself. These gradually collect on freezing objects with which they come into contact, and are there transformed into those fairylike fringes that transform branch and

leaf and gutterspout into things of almost unearthly beauty. When it happens that the fog clears and the sun comes out the world seems almost too lovely for human habitation. To have seen it once and to remember is compensation for many of life's trials.

'Hey, ho, the wind and the rain!' sang Feste, and like all Shakespeare's fools was less of a fool than he looked, for winds are responsible for most of the rain in temperate climates, and the kind of wind determines the kind of rain, though its presence is not always very evident. Spenser's rain, 'The ever drizzling rain upon the loft, much like the sowne of murmuring bees', the rain that in districts where the air is normally somewhat moist—as in the British Isles—is likely to continue for hours, is formed by a steady upward current set up by the collision of two converging winds. Like Portia's gentle rain from heaven it falls upon the place beneath, and usually in rather small drops, the size of which is determined by the speed of the current. A drop $\frac{1}{250}$ of an inch in diameter can fall through an upward current of two miles per hour. If the current is more leisurely the drop is smaller and we get a mere drizzle; if it is faster the drops are larger and the weather is apt to be stormy. It is in the fore part of a depression, where the warm air current is climbing slowly over the cold current, that steady drizzling rain occurs. When the centre of

the depression has passed stormy showers occur, for here the cold current is taking the initiative and is pushing the warm current upwards much more rapidly.

Mountain ranges are a very important factor in diverting air currents upwards and so causing them to expand and cool; and where mountains lie in the path of prevalent moist winds, such as the Westerlies and the monsoons, rain is very frequent. It is heaviest on the windward side, and less heavy on the leeward slopes. By the time the wind reaches the plains beyond it has given up most of its moisture, and so blows as a dry wind in spite of its watery origin.

The rainiest district in England is Seathwaite in Cumberland, where the average is 130 inches per annum. Here the Westerlies blow landwards from the Irish Sea against the bastions of the fells, and are turned upwards to let fall their excessive burden of moisture on the Cumberland and Westmoreland hills. Beyond the mountains the counties of Northumberland and Durham receive less than their share of rain. In the same way the mountains of the west of Scotland and Wales, and to a lesser extent the Devonshire moors, steal the rain from districts lying to the eastward, and when anything like a drought occurs in England the districts that suffer are the Midlands, East Anglia, and the Home Counties. The average rainfall over England and Wales amounts to nearly

seventy thousand million tons of water per annum, and shortage of water seems difficult to explain when during a drought it is possible in a few hours' run in car or train to pass from scorched, iron-hard meadows to lush green fields. The Cretans had evolved a very efficient system of aqueducts over short distances some 3,500 years ago. Our own system has incorporated improvements and is no doubt more efficient, but the problem of carrying water from the rainy west side of the country to the eastern districts must be a more difficult one than it appears to the uninitiated or it would have been solved long ago.

The wettest place in the world is Cherrapunji, in Assam, where the average rainfall is between 400 and 500 inches per annum. Of this, 275 inches falls during the three summer months when the wet monsoons are blowing up from the Indian Ocean against the slopes of the Himalayas, and as much as forty inches have been known to fall in one day. Compared with this London, with its twenty-five inches per annum, and New York, with 42·8 inches, are arid.

Other regions of heavy rainfall due to the presence of mountains are the Rockies in California and the Andes in South America. Both these ranges are partly in the zone of the Westerlies and partly in that of the Trades, and it is the areas where the Westerlies blow that have an excessive rainfall. The plains that lie to

the eastward are consequently robbed of their rain supply and the deserts of Utah, east of the Rockies, and of Tamarugal and Atacama, east of the Andes, are the result.

The only type of rain that is not associated with wind is convectional rain, and even this cannot be altogether dissociated if a vertical current has any right to the name of wind. The vertical current that causes convectional rain is not due to converging horizontal winds but to the heating of masses of moist air by radiations from the earth. This air rises rapidly, and the small drops that are formed in it are carried upwards, growing larger as they travel, until they become large enough to fall through the upward current in violent showers of large raindrops. These, in temperate latitudes, are the April showers towards which even those who have a strong aversion from rainy days are often indulgent. They last for so short a time, seldom for more than an hour; on the warmed earth they dry quickly, and the bright periods between are all the brighter by contrast with the storm. Incidentally, as all landscape painters are aware, colour values vary enormously with the state of the air. It is an ever-changing veil imposed between the eye and what it looks upon, of whose existence we are only vaguely conscious. Distance is not a mere matter of perspective, as the Chinese, slightly contemptuous

of such mathematical tricks, knew very well. It is a matter of atmosphere, and of a moist atmosphere at that. In an excessively dry climate background has a way of intruding on foreground, and looks a little out of place to eyes accustomed to more modest behaviour. Even the blue of the sky is an atmospheric effect, and in the rarer air of the stratosphere changes to a deep violet. In outer space the sky is dark except for the light of the stars. Temperament is much influenced by the state of the atmosphere. The tranquil tones characteristic of the English climate have a sobering effect on the mind, then comes an April shower, a rain-washed sky, and suddenly colours become vivid and clear, and life exciting. But it is too much to expect a Britisher to attribute his sudden optimism to the stimulating effect of an April shower.

The summer thunderstorm is associated with convectional rain, and most of the rain in tropical climates is of the same nature. Tropical rain, however, unlike convectional rain in temperate climates, may continue for long periods, for the heating of the earth is continuous, and clear skies are rare. In the Doldrums belt, where there is little wind to disturb the steady functioning of convectional currents, there is a belt of almost perpetual rain.

'Squall' is the name given to the short sharp shower that occurs when a cold wind forces a warm current

of air rapidly upwards, and is characteristic, in temperate climates, of the weather in the rear of a travelling depression.

A 'cloudburst' is a still heavier rain-storm of even shorter duration, and it has not much to do with clouds and nothing to do with bursting. It is due to the sudden cessation of a swift upward current heavily laden with water-drops, which, although they are of considerable size, have not yet fallen because of the velocity of the current. Suddenly the up-draught pauses, the raindrops lose their support, and, instead of making their way soberly downwards against a nicely balanced air resistance, they fall precipitately to earth as if they were spouted from a shower-bath.

The word 'cloudburst' is also used to describe the collapse of a waterspout when it reaches the shore. In fact the word is apt to be applied to any sudden heavy fall of rain, and probably came into use at a time when clouds were believed to be as solid as the old masters painted them, and capable of bursting and dropping their contents as if they were elaborately constructed tanks. If we were to believe the evidence of film plays we might still think cloudbursts more common than in fact they are. But no doubt the gentle rain, when not dropped from heaven, is difficult to manufacture.

A 'waterspout' can hardly be called rain, and

should perhaps have found a place amongst the winds but that its name sounded inappropriate. Winds and clouds and rain are so closely related that their segregation into separate chapters is a literary convenience only and the exact boundary of each subject must not be insisted upon. The waterspout resembles the tornado, but whilst a tornado occurs over land a waterspout can only be formed over a large stretch of water. It is caused by a spinning column of air that revolves with such velocity that an area of very low pressure is created in its centre, into which water and water vapour are drawn up, sometimes to a great height. In a tornado it is not water, but water vapour that is drawn upwards through the central funnel, and the lower portion of the column is formed of dust and débris. As the air rises within the tornado and at the same time expands towards the centre, the vapour condenses with great rapidity, and although the air current is all the time whirling upwards its actual ascent is less rapid than the rate of condensation owing to its spiral direction. A well-developed tornado is funnel shaped and tapers towards the earth, as if it were suspended from the cloud above it.

Snow is formed in the same way as rain, except that precipitation takes place at a different temperature. If this is below freezing-point vapour is condensed in the form of minute hexagonal crystals of

the same nature as those that form hoar-frost. If they fall through warm currents of air they melt again and fall to the earth as rain, or they may, if the air is warm enough and dry enough, evaporate altogether. If neither happens the tiny crystals collect together in the same way as the droplets that go to make a raindrop; but in so doing they do not lose their identity. Each snowflake consists of a collection of crystals joined together so differently and forming so many different designs that it is said that no two snowflakes are exactly alike.

Sleet, which is partly snow and partly rain, can be formed in either of two ways. It can precipitate as snow in an upper layer of cold air, and become partially melted as it falls through a layer of air that is just above freezing-point; or it can precipitate as rain in an upper layer of comparatively warm air, and become partially frozen by falling through a cold layer of air.

Hail differs from snow in that it is composed mainly of frozen water, while snow is composed entirely of frozen water vapour. There is a type of soft hail that is nothing more than a raindrop that has fallen through a freezing current of air and become frozen, but this is not true hail. A real hailstone has an onion-like structure, and is formed only when upward currents of air are very strong. Its central core is soft and is formed at a very high altitude, often as much as

five miles above the earth, either in the same way as snow crystals or as a frozen raindrop. When it is large enough to fall it drops through an updraught that is laden with super-cooled water-drops, i.e. drops that have reached freezing-point without having become frozen. As these drops are annexed each in turn becomes frozen into a shell of ice, one on the top of another like a Chinaman's coats. As the up-draught is a swift one the journey to earth takes a long time, for it must be made relative to the speed of the current and also to the distance from point to point. During the course of the journey the coats of ice continue to collect and the size of the hailstone increases accordingly. In Europe the average size of hailstones is about that of peas, but they are sometimes as large as golf balls, whilst in sub-tropical regions they occasionally attain the size of tennis balls.

If the up-draught through which the hailstone is falling increases in intensity the hail will be carried up again into the layer of air where water vapour condenses directly into ice crystals. Here it will acquire a soft coat of the same nature as its core, and this will be overlaid, when its downward journey continues, with hard coats. If great care is exercised it is possible to cut a hailstone in two, and some idea of its history can be deduced from the number and order of the hard or soft shells of which it is composed.

VI

CLOUDS

Classification of Clouds into Families and Genera

FAMILY A: High clouds (usually between 20,000 and 40,000 feet; mean lower level, 20,000 feet)

Form (*b*) 1. Genus Cirrus
2. Genus Cirrocumulus
Form (*c*) 3. Genus Cirrostratus

FAMILY B: Middle clouds (usually between 6,500 and 20,000 feet)

Form (*a*), Form (*b*) 4. Genus Altocumulus
Form (*c*) 5. Genus Altostratus

FAMILY C: Low clouds (mean lower level close to the ground; mean upper level, 6,500 feet)

Form (*a*)
Form (*b*)
: 6. Genus Stratocumulus (usually between 1,500 and 4,500 feet; sometimes as low as 500 feet or as high as 8,000 feet)

Form (*c*)
: 7. Genus Stratus (usually between 500 and 2,000 feet; sometimes practically down to the surface; sometimes as high as 4,000 feet)
: 8. Genus Nimbostratus

FAMILY D: Clouds with vertical development (mean upper level that of the cirrus, mean lower level 16,000 feet)

Form (*a*)
: 9. Genus Cumulus (usually between 2,000 and 5,000 feet; sometimes as low as 1,000 feet or as high as 8,000 feet)
: 10. Genus Cumulonimbus (usually between 2,000 and 5,000 feet, sometimes as low as 1,000 or as high as 8,000 feet)

It is strange that the ancients, who delighted in giving names to so many things and in weaving histories

to explain their origin, found for the clouds neither names nor history. Nameless things drift vaguely through the consciousness, and, inadequate though words may be to express beauty or truth, they are yet necessary to communicate it, and so to hand on and enrich experience from age to age.

It is little over a century since clouds first received their names. Perhaps that is why they are still new to many of us. For the landscape we have words enough and too many, but the cloudscape we find difficult to describe, and we cannot fix it in our minds because the significant words are strange to us. It is time we took possession of this vast realm of beauty. The landscape may belong to our neighbour, but the sky is equally ours and his.

Clouds were first classified in 1801 by the French naturalist Lamarck, but the terms he used, being French, had only a very limited appeal and found no general acceptance. Two years later Luke Howard, a London chemist, published a paper in Tilloch's *Philosophical Magazine*, 'On the Modifications of Clouds', in which they were given names derived from the Latin, applied with such taste and judgement that his classification, with only slight additions and alterations, was adopted by the International Meteorological Committee, and is in general use to-day.

Luke Howard's terms were descriptive only of cloud

forms, and it could not be otherwise, for the process of cloud formation was not then known. It was discovered in 1880, sixteen years after Howard's death, by John Aitkin (1839–1919), an amateur meteorologist, who, fortunately for the world, was unable to follow a more arduous profession on account of ill health. His devotion to meteorology has been recognized in the perpetuation of his name in the term 'Aitkin nuclei', given to the condensation nuclei described in the previous chapter.

Classification according to shape may appear more artistic than scientific, but actually it is the only practical one, as certain types of cloud may originate in several different ways and it is occasionally impossible to discover how a particular cloud has originated. Cloud forms, on the other hand, fall into definite groups, corresponding to some extent to their altitude, and after a little practice it is not difficult to place them correctly. The habit, when acquired, of greeting each cloud by name brings a peculiar satisfaction, perhaps because it directs the eye and mind to contemplate critically a region where criticism never disappoints.

Ruskin, in *Modern Painters*, writing in 1843, from visual observation divided the clouds into three regions, the region of the cirrus, the central cloud region, and the region of the rain cloud. The International

Meteorological Committee, writing in 1934 with a scientific rather than an artistic outlook, divided them into families, high clouds, middle clouds, and low clouds, and added a fourth family, clouds with vertical development. The first three families correspond very closely to Ruskin's three regions, and are also closely related to the three regions of maximum cloudiness. It is possible for clouds to form at any altitude up to the limit of water vapour, but they form more frequently at certain levels, and as a knowledge of these levels is often of help to the beginner when identifying clouds they are worth remarking upon.

The uppermost level of maximum cloudiness is the lower margin of the stratosphere, and it varies with latitude as the height of the stratosphere varies. At the Poles it is about five miles high, between six and seven miles in temperate latitudes, and over the equator about nine miles. In the stratosphere itself clouds cannot form because it is above the limit of convection, that is to say air no longer rises and expands, and temperature has reached a point of equilibrium. It is above the stratosphere, where temperature again increases, that mother-of-pearl clouds have been observed, but these are so very unusual that they cannot be included amongst ordinary cloud forms.

The general level of clouds varies in different latitudes in the same way as the height of the stratosphere. Where height is given it will be estimated, for the sake of conciseness, for temperate latitudes only, unless otherwise stated, and must be adjusted by the addition of about two miles for the tropics and the subtraction of from one to two miles for Polar regions.

The second maximum level of cloudiness is about five miles above the earth. Both first and second levels are included by Ruskin in his 'region of the cirrus', and in the *International Cloud Atlas* in the high clouds, whose mean lower level is given as $3\frac{1}{2}$ miles. The third level is between 2 and $2\frac{1}{2}$ miles, and constitutes Ruskin's central cloud region. It includes the middle clouds, the mean lower level of which is $1\frac{1}{4}$ miles, and mean upper level $3\frac{1}{2}$ miles. The fourth level of maximum cloudiness is about four thousand feet above the earth, about the height of Ben Nevis. It is included in Ruskin's region of the rain cloud and in the *International Cloud Atlas* among the low clouds, which extend from close to the ground to a height of about a mile and a half.

In the International Classification clouds are divided into three types, and each of these may appear at nearly all levels. The types are:

(*a*) Isolated, heap clouds with vertical develop-

VERY SMALL FINE WAVELETS OF ALTOCUMULUS

ment during their formation, and a spreading out when they are dissolving.

(*b*) Sheet clouds which are divided up into filaments, scales, or rounded masses, and which are often stable or in process of disintegration.

(*c*) More or less continuous cloud sheets, often in process of formation or growth.

Ten different cloud forms are then described. Most of them may be formed at more than one level, and it would therefore be incorrect to say that the list begins with the highest clouds and descends in order to the lowest. Nevertheless most clouds have their characteristic levels, and in this sense the list is an orderly one.

The highest of all are the cirrus, the 'curl' or 'tuft of hair' clouds. In certain favourable conditions they may be formed at other levels, but as a general rule they are at greater heights than any other cloud, namely between three and a half and seven miles. They are consequently the most tenuous and the coldest of clouds, for they exist in a region where water vapour is scarce and temperature far below freezing. They are generally formed of minute ice crystals, blown across the sky in gossamer threads that catch the rose tints of dawn or sunset without concealing the blue of the sky, and through which the sun shines, but with a softened brilliance. The official description is as follows:

'1. *Cirrus* (*Ci.*).—*Detached clouds of delicate and fibrous appearance, without shading, generally white in colour, often of a silky appearance.*

'Cirrus appears in the most varied forms, such as isolated tufts, lines drawn across a blue sky, branching feather-like plumes, curved lines ending in tufts, etc.; they are often arranged in bands which cross the sky like meridian lines, and which, owing to the effect of perspective, converge to a point on the horizon, or to two opposite points (cirrostratus and cirrocumulus often take part in the formation of these bands).'

The origin of cirrus clouds is the further cooling, by ascent and expansion, of air already cold and therefore holding but little water vapour. 'Mares' tails' are formed from a little puff of rising cloud spun out into threads by the descent of the snow of which it is formed or by the increase of wind velocity with elevation.

Cirrus clouds are very useful to the weather prophet, for they are reliable weather signs. When they appear in an otherwise clear sky, and then gradually evaporate into the blue, fair weather is probable for several days, for the air is evidently dry. When, however, they gradually thicken into a formless sheet of cloud, rain or snow is probable within a few hours.

Cirrus clouds may be further described, according to the particular form they assume as:

Cirrus filosus (threadlike).

Cirrus implexus (woven or twisted).

Cirrus tufted.

Cirrus tractus (drawn out, as wool is drawn out for spinning).

Cirrus uncinus or caudatus (hook shaped, or like a tail).

Cirrus plumeus (downy or feathery).

Cirrus inconstans (changeable or capricious).

Cirrus banded (Noah's Ark).

Some of these terms may be used to describe other clouds, but most of them are most suitable to the fragile and ethereal cirrus.

The second type of cloud in the cirrus region is the cumulus or heap cloud which makes up the familiar mackerel sky. These flocks of little clouds are known in France as sheep, in Germany as lambs, and by the International Committee as:

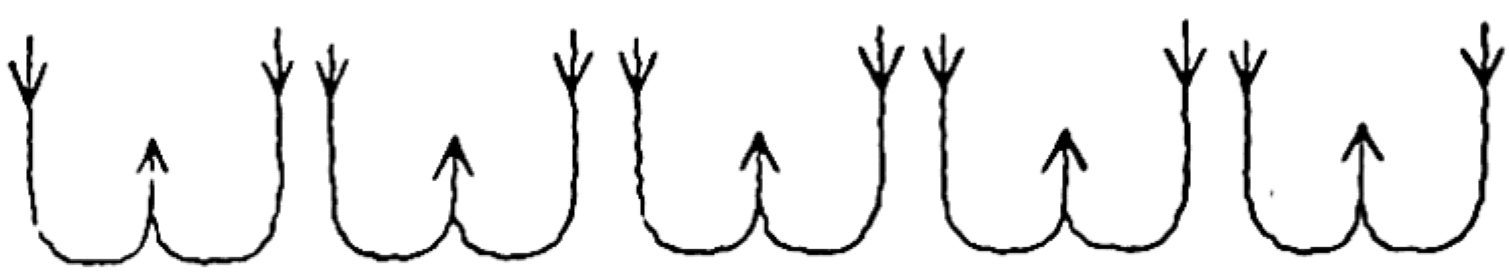
'2. *Cirrocumulus (Cicu.).—A cirriform layer or patch composed of small white flakes or of very small globular masses, without shadows, which are arranged in groups or lines, or more often in ripples resembling those of the sand on the sea shore.*

'In general cirrocumulus represents a degraded state of cirrus and cirrostratus, both of which may

change into it. In this case the changing patches often retain some fibrous structure in places.

'*Real cirrocumulus is uncommon.* It must not be confused with small altocumulus patches on the edges of altocumulus sheets.'

Cirrocumuli are not always as orderly as in the mackerel sky; they may be blown together into a more or less uniform cloud, or they may form no more of a design than the broken curds in milk, from which they take their homely name of 'curdled sky'. It is very important to remember that they are always very shallow, as can be seen both from the fact that



DIRECTION OF THE AIR CURRENTS IN THE FORMATION OF CIRROCUMULUS CLOUDS

they are practically without shadow, and that the outline of the sun or moon can be clearly seen through them.

They are formed at about the same height as cirrus, where water vapour is still rare and cloud fabrics insubstantial, by the cooling of the upper surface of the cloud by loss of heat by radiation into the clear air above. When there is little disturbance from wind the cool layer at the top sinks through the warmer layer

below, and meanwhile the warmer air rises through it and the cloud falls apart into flakes.

These high clouds, instead of taking the form either of tufts or of flocks may spread out into a filmy veil covering a large portion, or even the whole of the sky. They are then:

'3. *Cirrostratus* (*Cist.*).—*A thin whitish veil, which does not blur the outlines of the sun or moon, but gives rise to haloes*. Sometimes it is quite diffuse and merely gives the sky a milky look; sometimes it more or less distinctly shows a fibrous structure with disordered filaments.'

It looks innocent enough, and when there are no other clouds in the sky few of us would think of setting out with an umbrella, and yet it is an almost infallible sign of approaching bad weather, and the usual herald of a depression. Whenever cirrus develops into cirrostratus a raincloud will soon appear over the horizon, and rain or snow will fall before long.

A little lower than the cirrus, but still at a great height, are formed the altocumulus clouds, which resemble in many ways the far less common cirrocumulus. Their altitude varies between one and a quarter and three and a half miles, and although water vapour in this region is still far from abundant it is less scarce than at the level of the high cirrus, and

the clouds formed are more substantial, as can be seen from their shadows. The shadows are very pure and of a bluish tint, an effect produced by distance. These clouds are the

'4. *Altocumulus (Acu.).—A layer, or patches composed of laminae or rather flattened globular masses, the smallest elements of the regularly arranged layer being fairly small and thin, with or without shading.* These elements are arranged in groups, in lines or waves, following one or two directions, and are sometimes so close together that their edges join.

'The thin and semi-transparent edges of the elements often show irisations, which are rather characteristic of this class of cloud.'

Very occasionally an altocumulus grows to a considerable height. It is then called Altocumulus Castellatus.

Altocumuli frequently form after sunrise on a clear morning in a layer of air that is humid on account of the evaporation in it of a previous layer of altocumuli. They may linger in the sky all day, but after sundown they vanish again, curiously enough because they then become cooler. The reason is this: as they cool, both by loss of heat by radiation and by evaporation, they cool the air in which they float, which promptly contracts and sinks, carrying the clouds with it. The sinking causes compression, which warms the air again,

and in the warm air the clouds evaporate and disappear, possibly to provide material for the formation of another flock of altocumuli when the warm air rises and cools next morning. It was probably this process that originated the French saying, 'La lune mange les nuages'.

The groups of both altocumuli and cirrocumuli have two marked characteristics, the flaked formation and the wave or ripple formation, and the two frequently combine to give the familiar mackerel effect. Wave clouds are caused by the movement of different currents of air in different directions and at different speeds; the currents are probably of different density and temperature and carry a different proportion of water vapour. There is a closer affinity between air and water than we always realize, and wind frequently moves, as water moves, in waves that become manifest when billow clouds are formed. In clouds of this nature the fabric comes and goes, as does the water in a wave, but the cloud remains, it may be for hours. As the air wave rises the air on its crest expands and cloud is formed; as it sinks the air is compressed and warmed, and the cloud evaporates, so that each crest is clouded, each trough is clear, but the actual fabric of crest and trough, the water-drops and the water vapour, pass on. For this reason the velocity of wind in upper regions must never be cal-

culated from the movement of billow clouds. When they move across the sky they do not move with the velocity of either air current concerned in their formation, any more than the sea moves with the velocity of its waves or of the wind that raises them, but with a speed that is something between the two.

In the central cloud region and formed at about the same height as the altocumulus is a cloud group that corresponds with the cirrostratus in the uppermost region. This is the altostratus. Unlike the cirrostratus it is not composed of ice crystals but of small water-drops and therefore does not give rise to haloes, but sometimes causes coronae. It is formed in a current of warm moist air when it flows over a cooler current in a horizontal direction. It may also be formed by the drawing out of part of the upper layer of a thunder cloud by a horizontal current of wind, or simply by the cooling of a layer of moist air. It is described as follows:

'5. *Altostratus (Ast.).—Striated or fibrous veil, more or less grey or bluish in colour.* This cloud is like thick cirrostratus but without halo phenomena; the sun or moon shows vaguely, with a faint gleam, as though through ground glass. Sometimes the sheet is thin with forms intermediate with cirrostratus (*altostratus translucidus*). Sometimes it is very thick and dark (*altostratus opacus*), sometimes even completely hiding the

sun or moon. In this case differences of thickness may cause relatively light patches between very dark parts; but the surface never shows real relief, and the striated or fibrous structure is always seen in places in the body of the cloud.'

It is useful to remember that whenever the word 'stratus' is used in connection with cloud it implies a horizontal layer, whether it is a mere gossamer veil, as in the cirrostratus, or the uniform layer of cloud-like fog that is the stratus proper—any cloud, in fact that is strewn over, or spread out across the sky like a coverlet. It may even consist of a layer of irregular masses as in the

'6. *Stratocumulus* (*Stcu.*).—*A layer or patches composed of laminae or globular masses; the smallest of the regularly arranged elements are fairly large; they are soft and grey, with darker parts*. These elements are arranged in groups, in lines, or in waves, aligned in one or in two directions. Very often the rolls are so close that their edges join together; when they cover the whole sky, as on the continent, especially in winter, they have a wavy appearance.'

When they form in great rolls marshalled in parallel lines across the sky they are called, in England, 'roll cumulus', and in Germany '*wulst cumulus*' or bolsters, an apt description that brings pleasant recollections of the warm comfort of the German feather bed—

once its unruly habit of falling off has been overcome.

Stratocumulus is a cloud that takes many forms, but it is not difficult to recognize, for it can be distinguished from the cumulus by the fact that it forms a layer, and from the stratus by the fact that it is lumpy. Cloud names, formed as they are by combination, are a little confusing at first, but become increasingly clear with use, until at last they appear so apt as to be inevitable.

The stratocumulus is probably formed by a combination of the processes of the rising of masses of warm air and the herding together of the clouds so formed by a horizontal wind. It belongs to the group of low clouds, and does not form at a greater altitude than eight thousand feet. Probably the warm air rises no higher because it meets an obstruction in the form of a layer of cool dense air, through which it is unable to pass, and so spreads out underneath it. It is impossible to be dogmatic about the causes that shape cloud forms, and for the most part they are guessed at rather than known. It is possible to form a cloud in the laboratory, but the cloud is, after all, only a shapeless fog, and the only other cloud that has been formed by human agency is the small cumulus that sometimes occurs above an out-of-doors fire.

The next cloud on the list is the stratus, with which

we are only too familiar. It is the least interesting and most depressing of clouds, and hems us in in winter when it is least welcome. Even the official description is a little taciturn:

'7. *Stratus (St.).—A uniform layer of cloud, resembling fog, but not resting on the ground.*—When this very low layer is broken up into irregular shreds it is designated fractostratus (frst.).'

Similar in appearance to the stratus is the rain-cloud, which until recently went by the name of nimbus, and was described as 'a dense layer of dark shapeless cloud with ragged edges from which steady rain or snow usually falls'. This description was somewhat at variance with the meaning of the word nimbus, of which the Latin dictionary gives a most sinister account, insisting that it is a black rain-cloud, a storm cloud, a thunder cloud, heavy rain, tempest or even misfortune or whatever, in the words of Vergil, can obscure the light of day, either literally or metaphorically. The intention of the International Committee was no doubt to limit its meaning to rain-cloud, but it was a much misunderstood intention, and gave rise to endless argument, which might well have been avoided if due emphasis had been allowed to the words 'steady' and 'usually'. In order to settle the argument the word 'nimbus' has been qualified by the descriptive addition of the word 'stratus', and

the definition revised and considerably enlarged. It now stands as:

'8. *Nimbostratus (Nbst.).—A low, amorphous and rainy layer, of a dark grey colour and nearly uniform*; feebly illuminated seemingly from inside. When it gives precipitation it is in the form of continuous rain or snow.

'But precipitation alone is not a sufficient criterion to distinguish the cloud, which should be called nimbostratus even when no rain or snow falls from it.

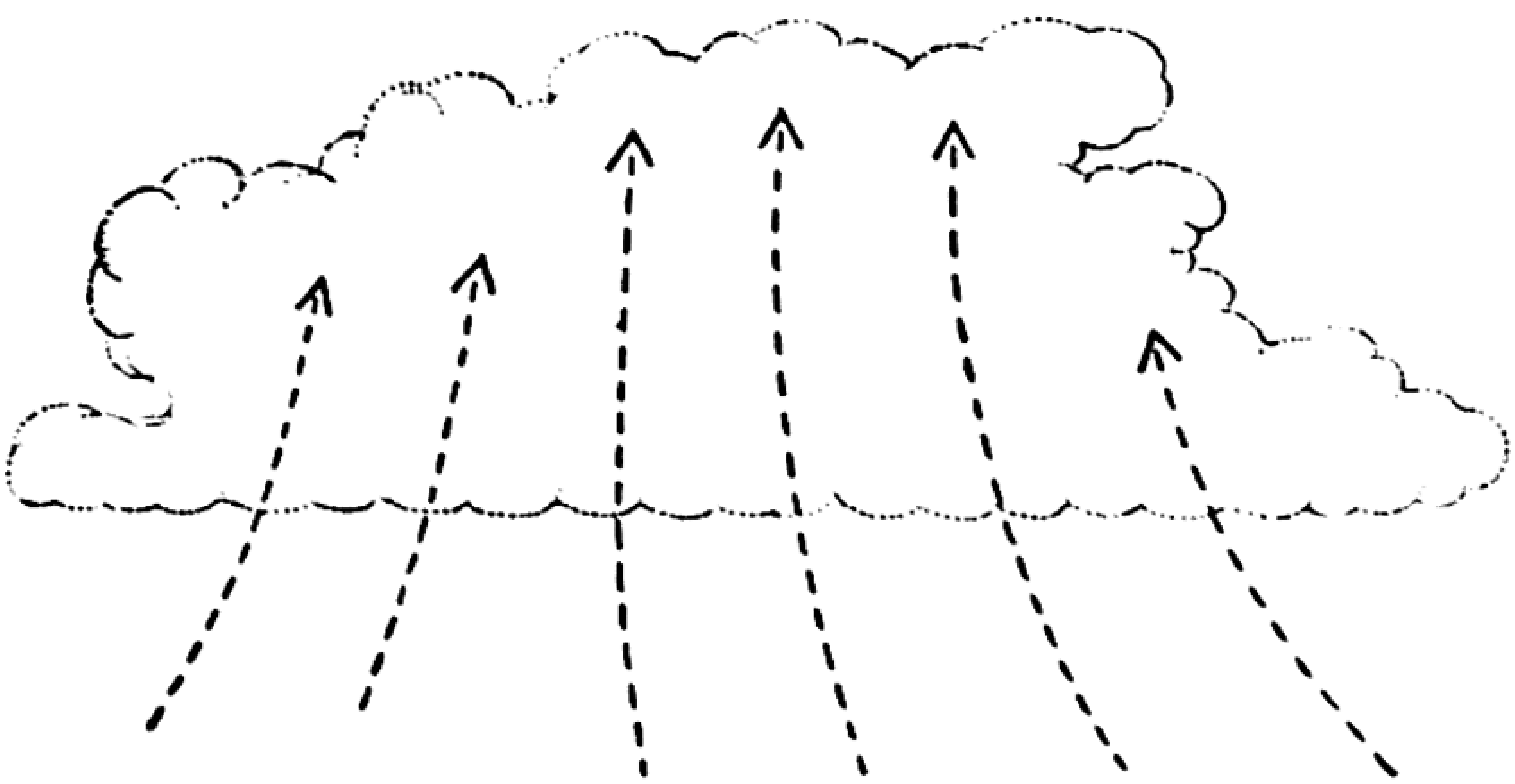
'There is often precipitation which does not reach the ground; in this case the base of the cloud is always diffuse and looks "wet" on account of the general trailing precipitation, *virga*, so that it is not possible to determine the limit of its lower surface.'

The nimbostratus is not formed in the swift vertical air currents that produce hail or heavy rain, but in the steadily rising air caused by converging winds, mountain barriers, or the over- and under-running of currents of different temperatures. It is a low cloud, like the stratus, and frequently rests on hill-tops little more than five hundred feet high, whilst it rarely leaves a mountain-top uncovered. With its ragged and often invisible edges it is an impossible cloud to draw. It lends itself, a little grudgingly, to washes of paint, but not to pen or pencil. If a drawing of a cloud is required the best model is the cauliflower or woolpack cloud, for there is an apparent solidity

about it, and a definiteness of outline as concrete as that of a house, or indeed of a cauliflower. The only trouble about it is that when it is drawn it is apt to look more like a cauliflower than like a cloud. It is described as follows:

'9. *Cumulus* (*Cu.*).—*Thick clouds with vertical development; the upper surface is dome shaped and exhibits protuberances, while the base is nearly horizontal.*

'When the cloud is opposite to the sun the surfaces normal to the observer are brighter than the edges of



TYPICAL AIR MOVEMENTS IN A CUMULUS CLOUD

the protuberances. When the light comes from the side, the clouds exhibit strong contrasts of light and shade; against the sun, on the other hand, they look dark with a bright edge.

'True cumulus is definitely limited above and below; its surface often appears hard and clear cut. But

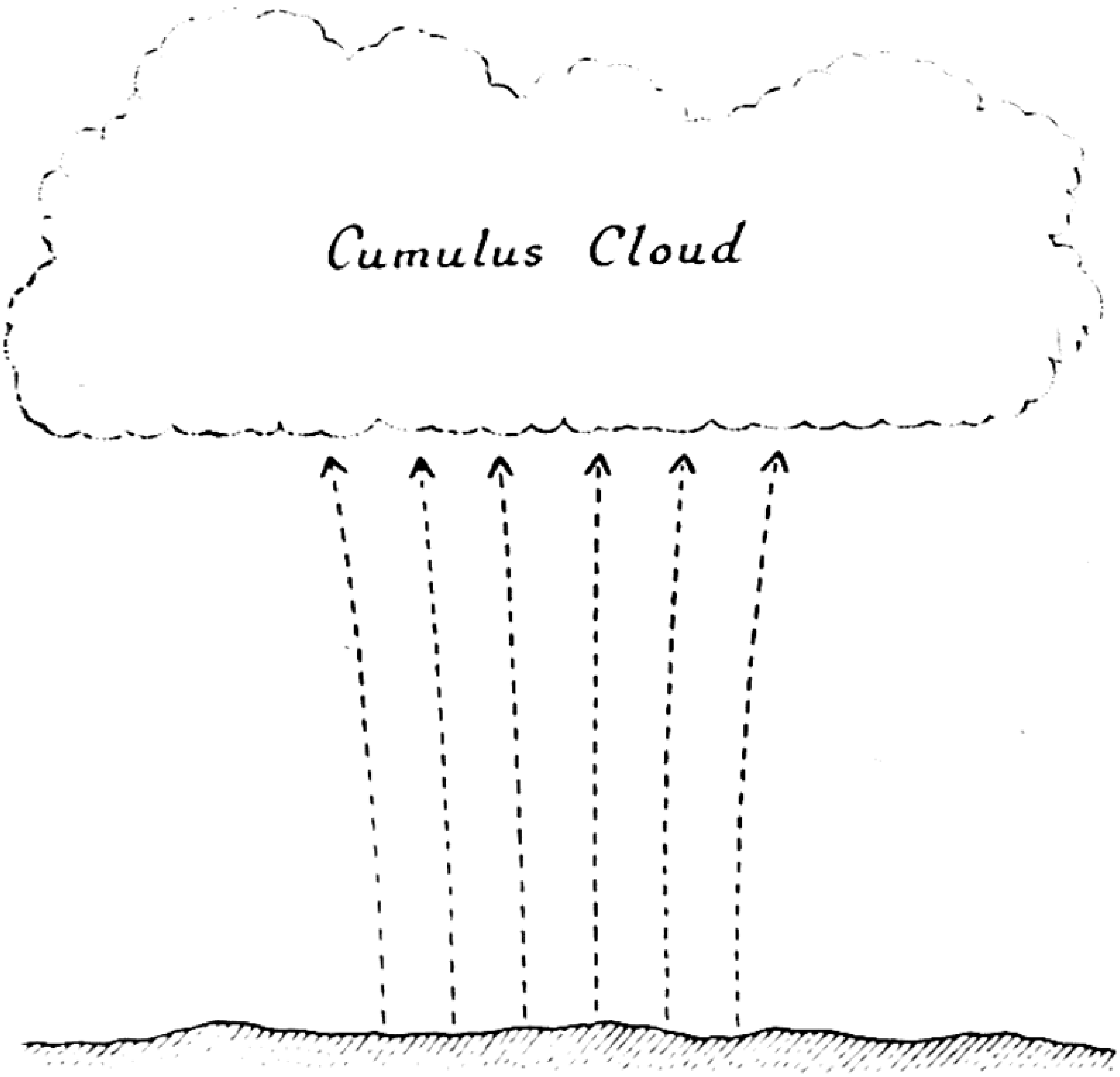
one may also observe a cloud resembling ragged cumulus in which the different parts show constant change. This cloud is designated fractocumulus (frcu.).'

Cumuli appear to be formed by ascensional movements of the air in the day-time, which are almost always observable. These ascensional movements are caused by the heating of the earth's surface, and cumuli are therefore warm-weather clouds, very common in the tropics and characteristic of summer in temperate latitudes. In the day-time a coast line can frequently be identified by its line of cumulus, but at night, when the earth has cooled, the line forms over the sea. The position of an island is often revealed by the stationary cumulus floating above it long before the island itself is visible. This cloud is generally of a lenticular shape, that is to say it is thickest in the middle and grows thinner at both ends. It is known as 'cumulus lenticularis'.

Cumulus clouds form at rather higher levels than stratocumulus, generally at about 4,600 feet. They are not very thick and their crests rarely rise higher than 6,000 feet.

In temperate latitudes small cumuli scattered about an otherwise clear sky indicate good weather, and are known as 'fine-weather cumuli'. When, however, a very large cumulus develops during the morning an afternoon thunderstorm is highly probable. Another

cloud that forms when thunder is about is the 'mammatocumulus', which has the appearance of a number of little bosses depending from the cloud above.



Air heated near ground

LIFT AS USED BY GLIDERS

These are probably due to the descent of puffs of cold air on to a stratus cloud below.

There are several cloud forms, not typically cumulus, but most conveniently grouped under that heading, that owe their characteristic shape to the deflection of wind currents by mountains. Some of these ap-

pear so frequently in certain districts, always occupying a similar position, that they are given a local name, and are regarded as sure weather signs. One of the most common is the 'crest cloud', and the most widely known example is the 'Table-cloth' that drapes the slopes of Table Mountain. The origin of crest clouds is the area of low pressure formed just over the leeward shoulder by the upward deflection of wind as it blows against a mountain slope. As the air current approaches this low-pressure area it expands and cools, and a cloud forms a little to the leeward of the crest in the upper part of the current. As it descends on the leeward side it becomes warm again and the cloud evaporates. Like the billow cloud it is in a constant state of condensation and evaporation, and although it is permanent in position the droplets that compose it are perpetually changing.

The 'riffle cloud' is formed in a similar way in an air billow analogous to the riffles that form in streams as water flows over an obstruction of rock. As the air rises in the riffle the cloud is created, as it falls the cloud vanishes, in the same way as billow clouds form and evaporate. The riffle cloud appears parallel with the crest cloud and a little beyond it, over the leeward valley. Occasionally a third cloud forms in a second air riffle, and on very rare occasions a fourth in a third riffle.

MOTHER-OF-PEARL CLOUDS OVER NORWAY

One of the best known riffle clouds is the 'Helm Bar' that forms over Cross Fell in the Pennines when the wind blows from the east. It takes its name from the fact that it forms a bar to the leeward of the Helmet Cloud, the crest cloud that forms over the summit.

The 'banner cloud' is similar to the crest cloud, and similarly formed, and another variant is the 'boa cumulus'. In the case of the boa the deflected air current passes round and not over the obstructing mountain, and the cloud encircles its shoulder, as, in the beginning of the present century, the feather boa encircled the shoulders of the chic Edwardian. No doubt it was before that date that the boa cloud that drapes the shoulders of Mount Etna was dubbed the Serpent.

Crest clouds, riffle clouds, and boa clouds are all locally supposed to be harbingers of bad weather, and they are likely to justify the belief, for they invariably reveal the presence of a moist wind.

There is one more cloud that is associated with cumulus, and although it is not uncommon it does not appear to be very well known. This is the 'scarf', a delicate cloud that forms above a rising cumulus when a thin layer of moist air above it expands. The more solid cumulus passes upwards through it, and the scarf cloud falls about it like diaphanous drapery.

The last cloud on the list is the cumulonimbus, which is formed in a swift up-rushing current of air, and is the most turbulent of clouds, suggesting in its appearance wild motion, just as the cirrus suggests serenity. The apparent serenity of the cirrus, however, is not due to lack of movement but to distance from the earth and steadiness of direction. The cumulonimbus is the deepest of all the clouds, and whilst its base is at about the same level as that of the cumulus its crest soars up to an average height of from two to four miles. In the tropics it may extent right up to the limit of convection—the lower boundary of the stratosphere. In the swift upper currents into which it rises it sometimes happens that its crest is combed out into threads of cloud similar in appearance to cirrus, and known as 'tonitrocirrus'.

Its official designation might be translated 'heaped up storm cloud', and it is described as follows:

'10. *Cumulonimbus (Cunb.).—Heavy masses of cloud with great vertical development, whose cumuliform summits rise in the form of mountains or towers, the upper parts having a fibrous texture and often spreading out in the shape of an anvil.*

'The base resembles nimbostratus, and one generally notices *virga*. This base has often a layer of very low ragged clouds below it (fractostratus, fractocumulus).

'Cumulonimbus clouds generally produce showers of rain or snow and sometimes of hail or soft hail, and often thunderstorms as well.

'If the whole of the cloud cannot be seen the fall of a real shower is enough to characterize the cloud as a cumulonimbus.'

VII

FOG

The chief difference, in fact the only real difference, between stratus cloud and fog is that of position. In one sense the difference in position may be that of the observer. Fog may become cloud by drifting a few hundred feet up a mountain side, and if the observer has climbed up the same mountain side he is likely to say that he has been caught in a mist or fog, whilst if he has remained in the valley below he will say that the mountains are in the clouds. If he is a purist, however, he must use the same word in both cases, and the appropriate word is cloud.

He must also use the word cloud when deep fog

from the sea has drifted over relatively warm land where the lower layer has evaporated, leaving the upper part hanging in the air in the shape of a layer of stratus. Such is the *velo* cloud that does so much to temper the morning heat of the sun in south California. Although it is not fog, neither is it typical stratus, for stratus usually forms at least five hundred feet above sea-level in a layer of relatively warm air that has been lifted up to that height by the flowing in underneath it of a stream of cool air.

Fog is formed in two different ways—radiation fog by the cooling of air near the earth through loss of heat by radiation, and advection fog by the drifting of a warm air current over a cooler surface. Radiation fog forms along the course of streams and rivers, over fens, and in moist mountain valleys, in the latter part of clear still nights in summer and autumn. In such localities the air becomes humid during the day owing to evaporation from moist surfaces, and when there is no wind to carry it off and mix it with dryer air elsewhere it lies heavily on the ground. During the night the earth cools rapidly and at the same time cools the air, and the excess moisture is precipitated in the form of fog or mist. When the sky is overcast the earth rarely becomes sufficiently cooled to allow the formation of fog, nor is it likely to form when there is sufficient wind to mix the moisture-laden air with dryer

air above. When the air is very still indeed, fog may be so shallow that cows can be seen wading only knee-deep in it, their cumbrous bodies floating ponderously on a sea of mist.

Advection fog is most common in winter and in coastal districts, especially where snow is lying, and is caused by a horizontal wind that drives the moist air from the sea over the relatively cold coast line. It is also caused by the drifting of warm air from above a warm ocean current into the neighbourhood of a cold current, for example from the Gulf Stream to the Labrador current, which is a region of frequent fogs. A third type of advection fog, common over Polar seas, is caused, somewhat contradictorily, by the drifting of cold air over relatively warm water. In this case the warm water continues to evaporate into the cold air, the temperature of which is too low to accommodate any increase in water vapour, which therefore, condenses into what is called 'frost smoke'.

Fog is a reliable weather sign. If it clears early the air above is evidently dry and clear, and the weather is likely to be fine. If it lingers late the air above is probably already saturated and rain is probable.

This does not apply, however, to city fogs, which are not so much a natural phenomenon as the combined effect of human activities and natural processes. The question is frequently asked, 'What is the diffe-

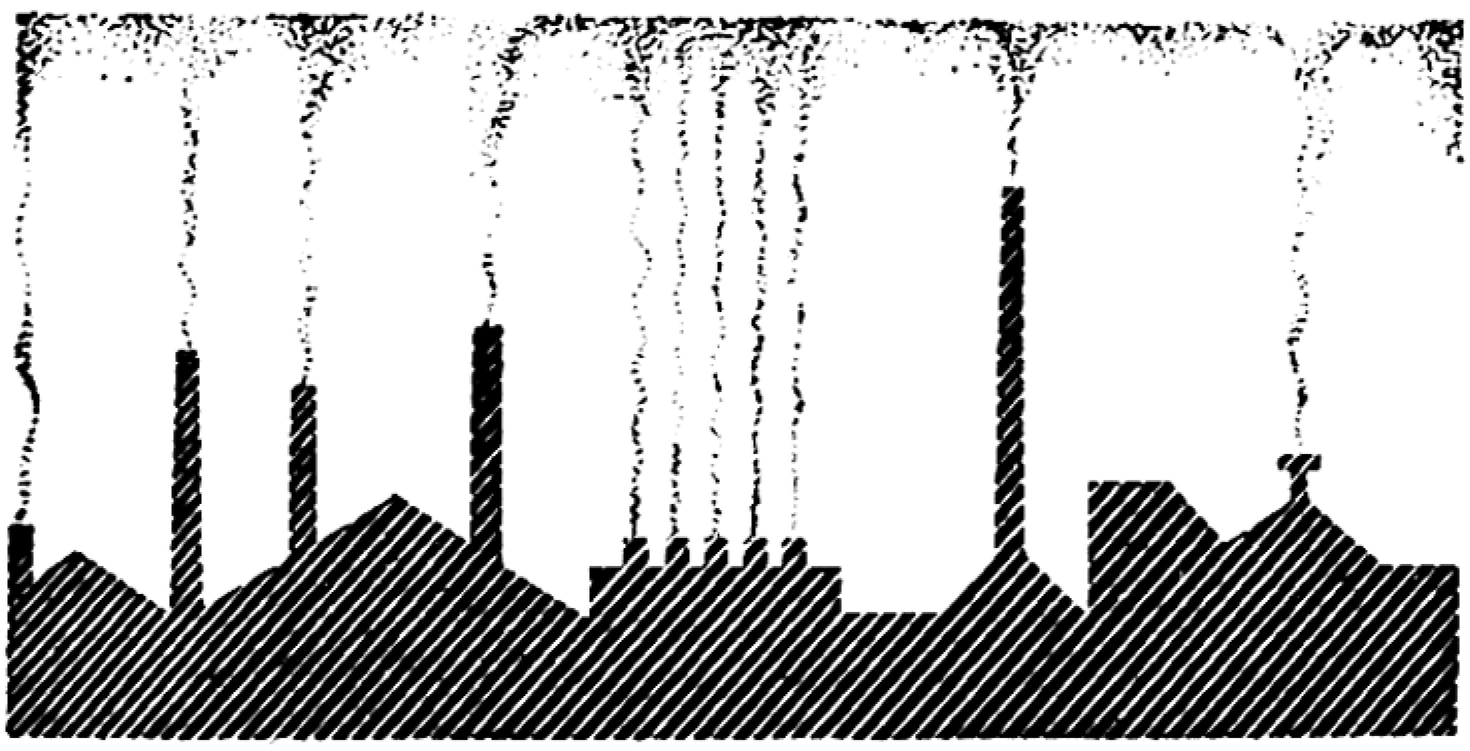
rence between a fog and a mist?' In some languages there is apparently no difference, the same word serves for both, but in English there are two words and a distinction is therefore required.

Meteorological offices deal in no subtleties. According to their definitions it is merely a matter of density. If a conspicuous object is invisible beyond a distance of 550 yards then there is a fog about. If beyond this distance, and up to an extreme distance of 1,100 yards a similar object is visible then there is no more than a mist or haze. For all practical purposes this definition must be accepted. At the same time a difference in quality must be recognized between what might be called a town fog and what might be called a country fog, the country fog having the characteristics that are associated in the mind with the word mist, in that it is not so dense and that it evaporates with greater rapidity.

This qualitative difference depends on the kind of nuclei upon which condensation occurs. Over the sea and in coastal districts these nuclei consist largely of salt particles caught into the air from spray, in country districts of vegetable and mineral dust and pollen. Droplets condensed on particles of this kind readily evaporate when the air becomes warm, and fog so formed rarely lasts for any great length of time.

In and about towns, on the other hand, the air con-

tains a preponderant number of hygroscopic nuclei (formed by the union of water vapour with the gases of ammonia and various oxides) and of 'soft' particles containing a minute quantity of coal tar, which forms a thin coat of oil round the droplets that form upon



FORMATION OF HIGH FOG

them. It is estimated that one puff of cigarette smoke contains as many as four thousand million separate particles of this nature, and town chimneys must belch them forth at the rate of thousands of millions per second. The sootfall on London alone is estimated at 75,000 tons a year, and on an average square mile of the London area it amounts to anything up to 400 tons. On this abundance of particles it is easy for a thick fog to form, but not so easy for it to disperse, for both hygroscopic and soft particles form a droplet that resists evaporation even when the air becomes warm and dry. Solar radiation can do little to evapo-

rate town fogs; nothing but a vigorous wind or a heavy shower of rain can disperse them.

Sometimes town fogs, although not very thick at ground-level, are so thick above that daylight is turned to a dim twilight. High fogs of this kind usually occur in winter during an anti-cyclone, and are caused by what is known as an inversion, i.e. a layer of air in which the temperature, instead of falling, suddenly begins to rise rapidly. The increase of temperature begins at a height of about 1,000 feet, and continues up to an altitude of about 3,500 feet. The thick layer of warm air acts as a barrier through which rising air is unable to penetrate, and so spreads out underneath as smoke spreads out in a room when it reaches the ceiling, carrying with it cloud that has already formed. Smoke and dust from the earth, which are normally carried to great heights in the rising air, and there dispersed by the prevalent strong winds, increase the density of the cloud, for, being unable to rise, they accumulate under the inversion layer, and spread over the city from which they came.

Country and sea fogs can never be done away with. However much they slow down our traffic they do not slow it down to the pace of a mere hundred years ago, and in any case we shall have to put up with them. But town fogs are not only inconvenient, they are harmful. To the healthy human being no other

weather in temperate climates is really noxious. Armed with watertight boots and a raincoat he should pursue his lawful occasions without let or hindrance from any weather except fog. But fog can do him no good, and with its extra burden of bacteria of all kinds may do him a great deal of harm. Even babies, those intrepid adventurers, should be kept indoors with closed windows when there is fog about. Stuffy air is not good to breathe, but fog is even worse.

In so-called civilized countries it is time for something to be done to diminish the evil of town fogs. The Smoke Abatement Society has a formidable name, but its work is truly philanthropic and deserves a wider appeal.

Fogs, being more accessible than clouds, and yet similarly composed, supply a good deal of information that applies to both about the size and number of the droplets they contain. A light fog contains about 1,000 droplets per cubic inch; the larger of these are about one thousandth of an inch in diameter, the average more like one two-thousandth of an inch, and many are smaller still. It would take over two thousand of them to make a chain one inch long. Dewdrops on cobwebs are Brobdingnagian in comparison. A thick fog contains at least 20,000 droplets per cubic inch, and may contain as many as a million, and yet the cubic inch is by no means crowded, as is evident

when the amount of water it contains is calculated. When visibility is 100 feet, a block of fog measuring $3 \times 6 \times 100$ feet contains about one-seventh of a glass of water, and this is distributed amongst something like sixty billion drops. It is easy to see that the formation of a raindrop of any considerable size from cloud droplets is not a very simple matter.

VIII

MOTHER-OF-PEARL AND LUMINOUS NIGHT CLOUDS

The list of clouds already given is complete in so far as it includes all the familiar clouds that are seen from day to day. But it makes two omissions; it makes little mention of mother-of-pearl clouds, and none at all of luminous night clouds.

These clouds are not formed in the troposphere, and they are both rare, but they do make their appearance from time to time and when they do so they make a deep impression on the beholder. Professor Størmer of Oslo recounts how he first saw mother-of-pearl clouds when he was a schoolboy of sixteen, and was so struck by their beauty that year after year he

scanned the heavens in the hope of seeing them again. It was thirty-six years before his zeal was rewarded, but since then they have made frequent appearances, and have been photographed many times, both in monochrome and in natural colours. In the process they have lost some of their mystery but evidently nothing of their charm, for those who have seen them write that their loveliness defies description. Rainbow colours, whether they play in opal, in oyster, in cloud, or even in coal tar, are so elusive that they seem to belong to the realm of faery rather than to the tangible world. They cannot be captured, for a touch destroys them. Perhaps that is the secret of their spell.

On mother-of-pearl clouds all colours of the rainbow play at once, coming and going, melting into each other in such subtle gradations that it is impossible to say where one colour begins and another ends. Sometimes a cloud may be suffused in one bright colour only, or it may gleam grey-blue or white.

The clouds assume many shapes. Frequently they are lenticular, sometimes they resemble the billow clouds of the alto-cumulus type; some drawings of them seem to be inspired by gigantic drifting leaves. If it is impossible for those who have seen them to find words for their beauty it would be ridiculous for one who has not been so favoured to attempt to do so.

It is hoped that these vague hints will be sufficient to inform the watcher what to look for.

They are day-time clouds, but appear also after sunset and before sunrise, for as long a time as they are not cut off from the sun's light by the earth's shadow. They must not be confused with what are known as 'iridescent clouds'. These are formed at the alto-cumulus level at an altitude of from between two to four miles, and possibly owe their colours to a large corona round the sun or moon which is only partially visible. Mother-of-pearl clouds are formed at a much greater height, usually between fourteen and a half and sixteen miles (twenty-three and twenty-six kilometres) above sea-level, sometimes even higher, and their rainbow colours are more varied and much brighter. From accounts of those who have seen both it appears that whatever similarity there may be in description, in reality the two types are very different and cannot be confused.

It is impossible to know in advance when to expect them. Each time they have appeared meteorological conditions have been almost identical, but they are conditions that rarely occur. The first essentials are a widespread depression of unusual intensity, accompanied by a rapid fall in the barometer. These conditions usually cause low rainclouds that completely shut out the sky, but on the occasions when mother-

of-pearl clouds have been seen the passing of the depression has evoked a *Föhn* wind which has compressed the air, raised the barometric pressure, and so warmed and dried the atmosphere that the rain-clouds have evaporated into it, leaving a clear sky. The sudden rise of temperature and pressure, notwithstanding the prevalence of a depression, have accompanied all the recorded appearances of mother-of-pearl clouds. It may be that they float over the centre of a depression more often than observations might lead us to suppose and that the low clouds that hem in our vision effectually prevent our seeing them.

In spite of the fact that they are far above the level where water vapour is present in any considerable quantity it seems likely that they are formed of water drops, but the drops must in that case be exceedingly minute. This conclusion has been deduced from the presence of an unusually large corona around the moon on one occasion when the clouds were visible. Coronae are known to be composed of water-drops, and the size of the drops can be calculated from the diameter of the corona, to which they are inversely proportional. It was calculated from approximate measurements that the drops were at most no larger than 0·0025 millimetres in diameter—of a size indeed to make cloud droplets immense in comparison, but large enough to float at those airy heights.

Noctilucent or luminous night clouds are also of rare occurrence, but not so rare as to warrant their being ignored, especially as they inhabit a region about which little information is available but much is desired. It was in 1884 that O. Jesse, working in Berlin, first drew attention to them, and shortly afterwards began to take measurements to determine their altitude, which appeared to be very great. A few years later Carl Størmer, then no more than a schoolboy, observed them in the night sky above Norway, and in the year 1909 he obtained his first photograph. In the years following they have been seen by observers in Germany, Poland, Russia, Norway, Sweden, Denmark, and Canada, and mention is also made of their appearance over the southern hemisphere, though this occasion is less well documented. They have been observed from one place or another almost annually, and always during the months of June, July, or August.

It is possible that they have been visible from Great Britain. Even if it must be assumed that they have appeared over northern latitudes only, Berlin is less than one degree farther north than London, Cambridge almost in the same latitude, and Leicester a little farther north than Berlin, so it does not seem likely that this country is too far south for observation.

LUMINOUS NIGHT CLOUDS SEEN FROM NORWAY

According to the accounts of those who have seen them they are as easily identified as mother-of-pearl clouds. Their great altitude cannot be mistaken, and it varies very little. It has been repeatedly calculated from a large number of photographs, taken by different workers, in different years and in different countries, and is always about fifty miles above sea-level. This is a little lower than the lowest recorded rays of Polar Lights, and is about the height at which the smaller shooting stars vanish. (Larger ones, however, penetrate another twenty miles through the atmosphere before burning themselves out.)

They usually make their appearance shortly after sunset, are most numerous after midnight, and may be seen until just before dawn. Their colour is a gleaming blue-white, through which the stars are visible as brighter points of light. Whilst the earth beneath is in darkness they are softly suffused with sunlight, and it has been noticed that the rays that illuminate them pass by the earth, at their nearest approach, at a distance of at least 18¾ miles, and therefore have not been filtered by passing through any great thickness of atmosphere. Clouds in such a position that the sun's rays must pass through the earth's atmosphere before reaching them are evidently as a rule invisible, but on one or two occasions a faint outline has been discernible. It seems that these clouds

are of such a nature that they can only be illuminated by ultra-violet rays, the short-wave radiations that are so largely absorbed by the earth's atmosphere.

The form of luminous night clouds is generally fluent, changing rapidly from moment to moment as if they float in a turbulent region. Sometimes they take the shape of gigantic billow clouds, measuring at least a mile from crest to crest. They move across the sky at a great pace; the lowest speed that has been recorded is 68 miles per hour, the highest about 680, and the average about 142. As a rule they follow an easterly to westerly direction, and on one occasion, judging from the fact that they were observed in central Norway, and thirty-three hours later in Canada, they seem to have travelled from Norway to Canada at a speed of approximately a hundred miles an hour. An exceptional case has been recorded by Jesse of clouds travelling from the south-west towards the north-east at a speed of 128 miles per hour.

These facts, however insignificant they may appear, are all of great importance, for movements of luminous night clouds provide reliable evidence of the movements of the upper air. Occasions offered of observing happenings fifty miles above the earth are rare, and yet until more is known about the behaviour of the upper atmosphere, movements of depressions and anti-cyclones cannot be perfectly under-

stood. We are like fishes confined to the ocean bed, speculating about the tides and ocean currents.

A question that any account of these clouds must inevitably evoke is, 'Of what material are they made?' Although it is probable that water droplets compose mother-of-pearl clouds it is almost inconceivable that at a height of fifty miles enough water vapour should be present in the tenuous atmosphere for the formation of luminous night clouds. It has been suggested that they are composed of volcanic dust such as floated above the earth after the eruption of Krakatoa. If this is so then some coincidence must be expected between large volcanic eruptions and the appearance of the clouds, but no such coincidence has been observed. In many important particulars their behaviour resembles that of shooting stars. These, like the planets, pursue regular orbits round the sun, and are encountered by the earth at definite intervals when the earth's path crosses the path of the meteoric swarm of which they form a part. So we encounter the Perseids in August, the Leonids in November, and, it might be added, luminous night clouds in July.

It seems probable then, that luminous night clouds consist of fine cosmic dust describing a course through inter-planetary space that once a year approaches within fifty miles of that of the earth. Their greater

profusion after midnight would then be accounted for by the fact that at that time the side of the globe from which they are seen is facing the direction in which it is travelling, and is therefore speeding towards the encounter. Their blue-white colour also provides an argument in favour of their origin in outer space, for it is characteristic of fine dust clouds, and not of clouds formed of water vapour or of ice-crystals.

A final argument in favour of this theory is the fact that their appearance has repeatedly coincided with that of meteoric showers. The most notable coincidence was in the year 1908, a year in which they were repeatedly observed and photographed in Russia, and also the year in which the greatest meteoric shower known to history fell in northern Siberia. This shower blasted an area, fortunately uninhabited, of several square miles. Had a similar shower fallen on London or New York, part of the population of those great cities would have been wiped out.

IX

RAINBOWS, HALOES, AND OTHER SKYEY APPARITIONS

It is no wonder that the ancients looked upon the rainbow as a miracle. Science, since their time, has changed our ideas of miracles and insists that the laws of nature cannot arbitrarily be put aside that they may be performed, but some of these laws are so marvellous that they may be said to constitute a miracle in themselves. Orderly minds prefer a law-abiding to an anarchic one and the rainbow remains a miracle to many of us still.

Some of the laws governing the propagation of light are familiar to most of us. Light may be:

1. *Reflected*, as in a mirror (as a ball is bounced back from a hard surface).

2. *Refracted*, i.e. deflected from its original straight path by entering a different medium, as in passing from air into water, or through layers of air of different density.

3. *Diffracted*, i.e. bent round an object, as can be seen from observation of the shadow of an object placed in a narrow beam of light.

It is also well known that white light is spread out into its constituent rainbow colours when its rays are variously deflected in passing through a prism, and that this process is involved in the emission of rainbow colours by the water drops that compose a cloud. All these generalizations, however, do not go far in explaining why a rainbow is a bow, and no other shape.

We each have our own personal and particular rainbow, as we each possess our own moon-path over the sea. Our proprietorship in the moon-path is more evident, for it stretches to our feet, and we know that another moon-path must reach the feet of our companion a few yards away. It is so also with the rainbow. The particular rays of light that voyage from the sun to the raindrop, are refracted in the raindrop, reflected from its farther boundary, and again refracted as they pass out and travel to the eye of the

beholder, must observe in each case angles of exact and definite dimensions. All the rays that reach the raindrop do not describe these angles, and consequently are not split up into rainbow colours, nor are they bright enough to be observed. Nor are all the drops in the cloud so situated that rays of light describing these angles will reach the eye of the observer. He is surrounded by potential rainbows, but he can only see one. It is only in drops occupying such a position that light from the sun can travel along this definite path, from sun to drop, into the drop and across it, back again and out, and then to the observer's eye, that the rainbow is manifest. Drops so situated lie in a semi-circle that has its centre on an imaginary line made by producing the line joining the observer's eye and the sun behind him. Hence the bow, and hence the fact that your bow is not your neighbour's bow, for another half-circle of drops must serve his turn, situated on the circumference of a circle that has its centre on a line produced from the one joining *his* eye and the sun.

If these attempts at explanation fall short of completeness it may legitimately be urged that so do most explanations of a rainbow. There is no shame in accepting it as the miracle that it is, with the simple assurance that it is a lawful miracle.

Inside the primary bow one or two supernumerary

bows occasionally appear, with the colours in the same order as in the primary bow, i.e. violet inside, but very much fainter. Outside the primary bow a secondary bow is sometimes to be seen with the colour order reversed, i.e. violet outside. This is formed of light that has been twice reflected inside the drop, instead of once. It is also refracted once on entering and once on leaving it, as in the primary bow.

The radius of the outer (red) band of the primary bow is approximately 42 degrees, and of the inner (violet) band $40\frac{1}{4}$ degrees. Of the secondary bow the outer radius is 54 degrees and the inner 51 degrees. When the sun is at an altitude of 42 degrees the path of the primary bow would lie below the horizon, but since the sun's rays are there intercepted by the earth there can be no primary bow. Rainbows must therefore be looked for in the morning and in the evening; they cannot be seen at midday except in very northern latitudes, where at noon the sun is still low in the heavens.

Rainbows occasionally assume less familiar forms. Ulloa's Ring is a white rainbow, usually formed in fog, or in a cloud situated very near to the observer, and composed of exceptionally small drops. Reflection rainbows, which are sometimes seen over a sheet of very calm water, are formed by rays of light that

illuminate falling raindrops after reflection in the water.

The ground rainbow lies flat on the earth as if it had fallen out of the sky and originates in dewdrops lying thickly on short grass. It is not semi-circular but forms an ellipse, parabola or hyperbola, varying in shape according to the height of the sun.

There are also lunar rainbows, but they are rare, and generally white. Only in the very brightest moonlight is colour faintly distinguishable.

The halo is another effect produced by the sorting out of light rays into their various colours, and in this case the circle has the sun or moon as centre. As in the rainbow, light is split up by refraction, and reflected, but not in water-drops; the tiny mirrors that reflect sunlight or moonlight in the form of a halo are the minute ice-crystals that compose cirrostratus clouds. This is a very important point, for it distinguishes the halo from the corona, which is formed by water-drops and by diffraction. Another important difference between the two is that the colours occur in the reverse order: in the halo the red band is inside the ring as it is in the rainbow, in the corona outside. The colours are brightest in the rainbow, less bright in the halo, and least bright in the corona, so faint, indeed, that they are often barely distinguishable.

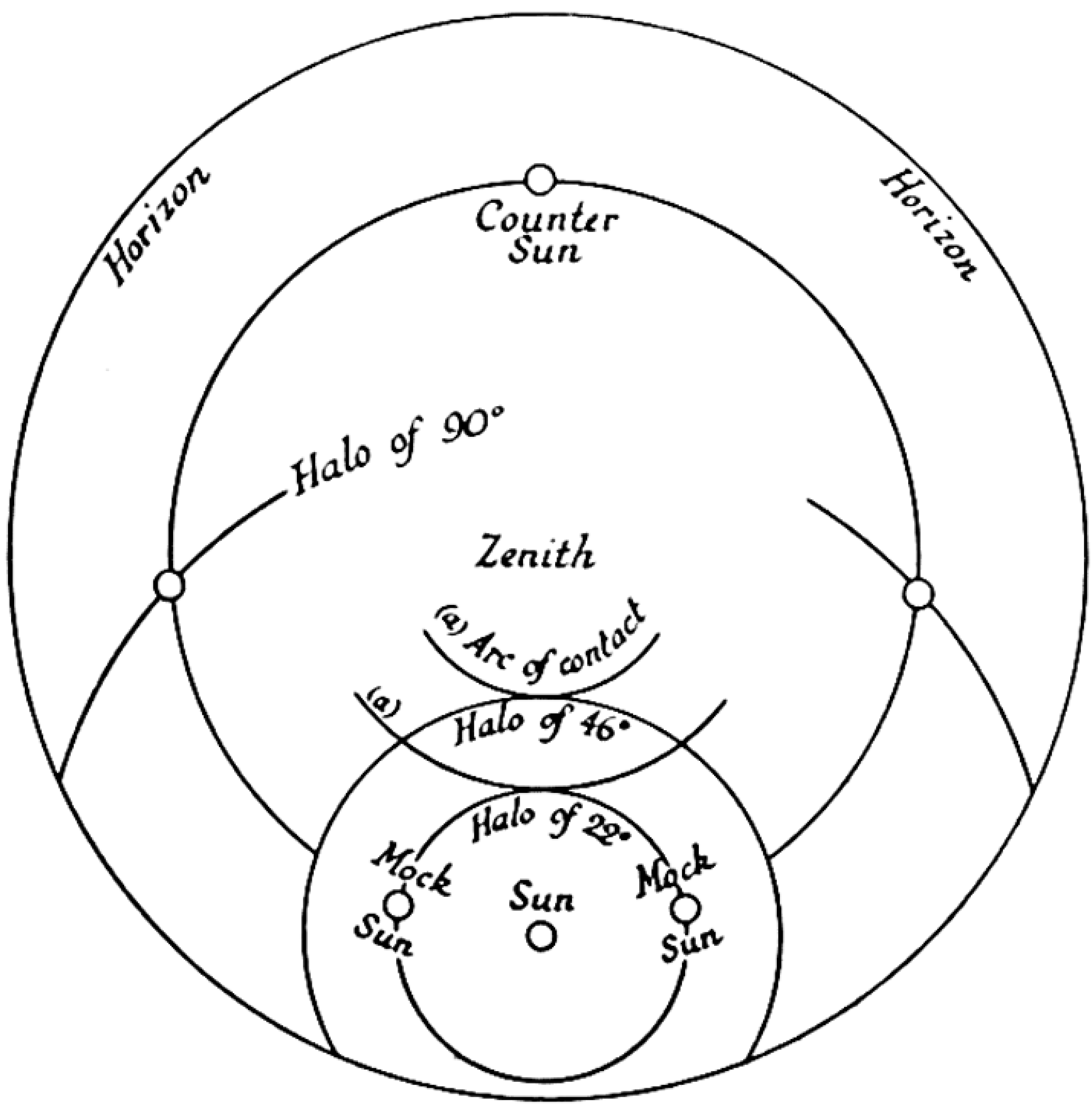
Haloes, like rainbows, are brighter when they are due to sunlight than when they are due to moonlight. They may appear as a complete circle, or as part of a circle, but the circles are of definite radius. The most common is the halo of 22 degrees (90 degrees being the measurement of the arc extending from zenith to horizon). This is the brightest halo; its red inner band is generally very bright indeed, the outer colours decrease in vividness and are seldom distinguishable beyond green, whilst the margin fades away into faint white light.

A halo of about twice this radius (46 degrees) is less common. It usually appears to be white, but when colours do appear they are arranged in the same order as in the halo of 22 degrees. Arcs of contact may appear in conjunction with either of these halos, and are very brilliantly coloured, especially at the point of contact. As a rule they are above the halo, but on rare occasions they have been seen below it and at the sides.

A still larger halo, the halo of 90 degrees, has been observed, but it is of very rare occurrence, and can be seen in its entirety only in the tropics, for if the sky is to accommodate it the sun must be in the zenith, and it will then encircle the horizon.

Another strange halo that encircles the sky when complete is the mock sun ring. It is always colourless,

and passes through the sun itself, or would do so if produced, for the portions near the sun are seldom visible. It is at the points where this ring intersects the halo of 22 degrees that mock suns (*parhelia*) or



HALO PHENOMENA

mock moons (*paraselenae*) are wont to appear. They are brilliantly coloured, red being on the side nearest to the sun, the other colours following in order as far as blue, which is indistinct, whilst violet is not visible. Sometimes a tail of light stretches out from the mock sun along the circle of the ring. Faint mock suns have

been seen at the intersection of the mock sun ring with the halo of 46 degrees, but they are unusual. More frequently a white mock counter sun can be seen on the side of the ring opposite to the sun, and others about half-way round. The mock suns may be visible whilst the ring that causes them is invisible. When the ring originates in moonlight faint mock moons may appear in similar positions as those described for mock suns.

The fiery cross is a halo phenomenon that is seen on rare occasions low in the sky either shortly after sunrise or shortly before sunset. It is formed by the conjunction of short portions of the mock sun ring with a sun pillar, and is due to the presence of cirrus haze in the atmosphere.

Various other rings and arcs appear in the sky from time to time, both in sunlight and in moonlight, but the town dweller knows little of them. They cannot be seen through the roof of a car, and buildings take up an undue amount of sky, but open spaces are still available, and the sky repays attention. It is unreasonable to complain that life is dull if no advantage is taken of the pageants provided by nature.

Coronae, like haloes, may be formed round either sun or moon, but they are more frequently observed round the moon. This may be because they are smaller in radius than haloes and nearer to their

source of light; when this is the sun their own faint light is outshone by its brilliance.

The corona is bounded on its inner margin by a brownish ring. This must not be confused with the red ring on the inner side of a halo, for the latter is the red band of the spectrum, which encloses it in due order, but the former is inside the violet band of the spectrum, and encloses a bluish-white ring known as the aureole. When a corona is complete the moon is surrounded by the broad field of the aureole, this is enclosed by a brownish ring of considerable width, and this in turn by the spectral bands in the order violet, blue, green, yellow, red, the colours sometimes repeated several times, which is never the case in a halo. It has already been mentioned, but it is an interesting fact worth repeating, that the diameter of a corona is determined by the size of the drops that form it, and is inversely proportional to the diameter of the drops.

The Brocken spectre is a cloud phenomenon. It is not peculiar to the Brocken but may appear on any mountain ridge, or indeed anywhere where the observer is between the sun and a bank of cloud, and is frequently seen from aeroplanes. With his back to the sun and facing the cloud the observer sees a shadowy form surrounded by coloured rings, or glories, as they are called. Like most ghost-ridden folk he is

looking only at his own shadow, and the coloured rings are caused by light diffracted backwards, as in a corona it is diffracted forwards.

There are skyey apparitions that are supposed to bring good fortune to the beholder, and others that have the reputation of foreboding ill. Of the former is the green ray that is sometimes seen when the sun has set in an exceptionally clear sky. Because the sun's light is bent as it passes from outer space into the atmosphere the sun is seen for a short time after it has actually passed below the horizon. Rays of different wave-lengths are bent in different degrees; green is bent at a sharper angle than either red or yellow, and is therefore still occasionally visible after the sun has dropped too low for the red or yellow rays to be seen. The green ray's reputation for good luck may be due to its association with fine weather, for the atmosphere must be exceedingly dry if it is to be seen.

A mirage is supposed to have a sinister significance. It certainly gives the observer the impression that he is not quite normal. But he need not be uneasy. It is not his eyesight that is playing him tricks but the atmosphere that is playing tricks with the light that reaches him from distant objects. Owing to unequal heating at the earth's surface the air between him and the object he is looking at is of unequal density, and as the light passes from one portion of it to another it

is bent, it may be many times, in the same way as when it passes from air to water. Remote objects lose their identity, and towards the horizon another landscape is built up, having scant resemblance to the scene that originates it. This mock landscape frequently includes distant lakes of blue water. These are actually patches of sky that appear to lie on the ground owing to the curve in the path of the light rays. In the same way pools appear across the surface of a metalled road just below the brow of a hill that bounds the horizon. When there are trees beyond the hill the mirage in the road is darker and more confused.

Another phenomenon that is popularly supposed to bode evil is the Aurora. It may have been its crimson streamers seen from the streets of Rome that Casca described as 'a tempest dropping fire', and inspired Calphurnia's horror-stricken tale:

> *Fierce fiery warriors fought upon the clouds,*
> *In ranks and squadrons and right form of war.*

Many will remember that it was seen in all its glory over most of Europe in the fateful year 1938, and will shake their heads. To such the ripe wisdom of Shakespeare's Cicero is commended:

> *But men may construe things after their fashion,*
> *Clean from the purpose of the things themselves.*

For the origin of Polar Lights is not short-sighted diplomacy but the emission by the sun of corpuscular rays (negatively or positively charged particles) and their impact with the atoms that compose the gases of the upper atmosphere. This has already been mentioned, and had this book been finished sooner the Aurora would have received no further notice, but the magnificent displays of 1938 have quickened interest in the subject, and some further explanation seems to be called for.

Auroral rays are of two types, those that appear at a very great distance from the earth, generally between two hundred and six hundred miles, in layers of atmosphere that are still transfused by sunlight, and those that appear in regions where direct sunlight is cut off by the interposition of the earth. The latter are most frequently about sixty miles above the earth, but on 27th January 1938 these normally low rays reached a height of 437 miles. No doubt had measurements of sunlit rays been secured on the same occasion these also would have attained record heights, but clouds intervened and no pictures suitable for calculations were secured.

It is plain that if corpuscular rays travelled in straight lines no auroral rays could be produced in regions lying in the earth's shadow, but as they consist of electrified particles they are affected by the

CUMULONIMBUS. AN EXTENSIVE ANVIL FORMED ABOVE THE MAIN CLOUD MASS

magnetic fields of both sun and earth, and consequently describe a spiral as they leave the one and as they approach the other. Near the equator their course lies too far above the earth to cause Polar Lights, near the Poles it is such as to provide frequent displays.

Much has been written about the crackling noises that some observers have heard during displays of the Aurora. Until recently scientists have regarded these noises as subjective, and purely the result of auto-suggestion. Professor Størmer, however, is inclined to take them more seriously. During the recent spectacle two of his assistants heard a noise which they likened to that of burning grass or of falling spray, for which they were totally unable to account except as having some connection with the Lights. Their description received confirmation from other reliable observers, and although it is clear that the sound could not come from the Aurora itself, but must originate in some lower part of the atmosphere, it was difficult to evade the conclusion that sounds and lights were in some way associated.

Light travels in space and there is no known limit to its voyaging, but sound travels in air and its journeys are confined to the atmosphere. The music of the spheres must be the music of motion, for no sound can leap the void between star and star, and outer space

must be utterly silent. It is impossible for sound to travel through the tenuous gases that are to be found several hundreds of miles above the earth; the origin of these noises and their connection with Polar Lights are therefore a complete mystery.

X

THUNDERSTORMS

We are so accustomed to think of electricity as a manufactured product bottled up in jars or batteries, or delivered to us like our water supply, that it requires a mental effort to realize that it is also in the air we breathe and on the earth we walk on. The sparks brushed out of the cat's tail savour of witchcraft, and when on cold mornings our hair crackles and stands on end we attribute it to our immense vitality rather than to the dryness of the air and the electrical nature of the atom.

The atom is so difficult to describe and has been so often described elsewhere that there is no need to

detail once more the intricacies of its structure. It is sufficient to remember that it consists of a central core or nucleus, which bears a positive charge, and of negative charges in the form of electrons that circulate about it at different energy levels in something like a cloud.

In the normal atom the positive charge on the nucleus is equal to the sum of the negative charges on the electrons, and the charge on the complete atom is therefore neutral. Atoms are so constituted, however, that in certain circumstances they tend to lose one or more of their outer electrons; the balance of charge is then upset and they become positively charged. Atoms in this state are said to be ionized, and are called ions, and the free electrons constitute negative charges of electricity unless and until they become attached to some other ion.

A positively charged body is one that has a deficiency of electrons, and a negatively charged body is one that has an excess of electrons. If two such bodies, insulated and equally and oppositely charged, are connected, electrons and ions will recombine and all signs of electrification will disappear. If, however, the charged bodies are at different potentials, electrons will flow towards the one that has a deficiency of them and will set up an electric current.

Potential may be defined as the amount of work

required to bring unit charge up to the charged body from a remote distance. The potential of a charged body may be increased either by concentrating the charge within a smaller area, or by giving the body a higher charge, and the body towards which electrons move is said to be at a higher potential. Potential corresponds to some extent to the pressure in a bicycle tyre. An equal amount of air exerts a greater pressure in a small than in a large tyre, and the pressure in any tyre can be increased by forcing in more air.

Potential is measured in volts, charge in coulombs, intensity of current in ampères, and the region subject to tension between charged bodies is called the field. Electricity is a difficult subject, and another analogy may be forgiven. The amount of water at the top of a waterfall corresponds to charge and is measured in coulombs; the height of the fall corresponds to potential and is measured in volts; the volume of the stream corresponds to current and is measured in ampères.

If two charged bodies at different potentials are insulated from each other by an insulating material no current passes between them; but if they are connected by a wire the current will pass along it, because wire is a conductive medium. Conductive mediums are made up of atoms whose outer electrons are easily

detached, and which can therefore pass on the electrical impulse transferred to them. Insulating mediums are composed of atoms whose outer electrons are more firmly held. Few substances are absolutely insulating, and technically speaking the distinction is one of degree, but of such a great degree that in practice the distinction can be treated as qualitative.

At one time the atmosphere was considered a non-conducting medium, and for practical purposes ordinary air can still be so regarded as long as it is recognized that charges do leak away through it very gradually. This leakage is due to ionization, and is rapid or slow according to the degree of ionization in the neighbouring air. The ionization of the atmosphere is caused by several agents, and their effect varies very much in different layers of the atmosphere and in different localities. The principal agents are:

1. Ultra-violet radiations from the sun.

2. Cosmic radiations from space.

3. Radiations from radio-active substances in the earth's crust.

4. Radiations from radio-active gases in the air.

These radiations detach electrons from the atoms that compose the air and divide them into ions and electrons, or positive and negative charges. Ultra-violet radiation and cosmic radiation are active chiefly in the upper layers of the atmosphere, and radiations

of radio-active origin are more active close to the earth.

The air is also ionized by the breaking-up of water-drops, either in waterfalls, in the splashing of rain against solid obstacles, or in rapidly ascending air currents. This process imparts a negative charge to the air, by detaching electrons from some of the atoms of which water is composed, and a positive charge to the residual water-drops. It is of minor importance in the normal ionization of the atmosphere but of great importance in thunderstorms.

The net result of ionizing processes in the atmosphere is that the air contains an excess of ions, that is to say it is positively charged. The earth, on the other hand, as the combined result of many other processes, has an excess of electrons and is negatively charged. In both cases, although the charge is considerable, it is distributed over such a large area that the potential gradient, or field strength, i.e. the rate at which potential changes with distance, is too small in normal conditions to allow a current to pass through the resistance of the air.

The potential gradient of earth and atmosphere varies. Over the whole earth it averages about 120 volts per metre; the mean potential gradient at Kew is 317 volts per metre; at Davos (Switzerland) it is 64 volts per metre, and over the oceans it is almost

uniformly 126 volts per metre. The positive charge in the lower six to ten miles of atmosphere is equal and opposite to the charge on the earth. These figures refer to fair weather only and are merely averages. During a drizzle the potential gradient is still only a few hundred volts per metre, but in a snowstorm it increases to about 10,000 volts per metre. During thunderstorms it varies between 10,000 and 20,000 volts per metre, and immediately under a thunder cloud it may be as much as 50,000 volts per metre. The direction of the field is completely reversed during dust storms; the air becomes negatively charged and the potential gradient is about 10,000 volts per metre.

These variations with weather are explained by the fact that condensation takes place on a large variety of nuclei. Approximately only one-third of the condensation nuclei present in the air are electrically neutral; the remaining two-thirds, in nearly equal proportions, acquire a unit positive or negative charge by the capture of either an electron or a positive ion, and when condensation takes place the droplet also is either positively or negatively charged. When these droplets run together in the formation of raindrops the charge is either neutralized by the addition of a charge of opposite sign or increased by the addition of a charge of like sign. As a general rule snow and drizzle are negatively charged, and rain-

drops have a preponderance of positive charge. The charge carried by rain or snow can be collected and measured; but when this is done, unless precautions are taken, it is apt to leak away through air that is ionized by the splashing of drops around the vessel in which the precipitation is collected.

The production of ions and electrons in the atmosphere and their conversion into charged droplets are the earliest stages in the formation of thunderstorms. It is evident that clouds must be composed of three types of droplets, neutrally charged, positively charged and negatively charged, and that in thunder clouds these must, in some way, become separated, either into different clouds, or, more usually, into different parts of the same cloud.

Exactly how this comes about is still somewhat uncertain, and the processes at work must be very complex. In the first place two conditions are necessary, a rapidly ascending current of air and a large moisture content. These conditions occur most frequently in the tropics, in warm weather in temperate climates, and in the neighbourhood of mountains. It is also generally agreed that thunder-clouds contain both large and small drops, and that these are oppositely charged.

A theory that has received wide acceptance is that in a thunder-cloud drops are formed that are larger

than 0·25 of a centimetre in diameter, and are therefore unstable. These, in breaking up, impart a negative charge to the air, and leave a positive charge on the water. The negative charges are carried upwards in the rapidly ascending current, and become attached to small drops that are carried back into the main body of the cloud, whilst the broken drops, now positively charged, re-form and continue their fall towards the lower part of the cloud.

According to another theory the upper part of a thunder cloud is positively charged and its lower part negatively charged. Now when a charged body is brought into the neighbourhood of another charged body charges of opposite sign attract each other, and therefore as the water-drops fall through the cloud the positive charge of each concentrates in its lower part, i.e. the part facing the negatively charged lower portion of the cloud. In a large drop falling rapidly through the rising air current this positively charged portion will attract and capture negative charges that the air carries to meet it, and so acquire a negative charge. Meanwhile the small drops, being lighter, keep pace with the ion streams, and being unable to make selective captures acquire a net positive charge.

A charged cloud, or part of a cloud, behaves like any other charged body, that is to say it will discharge towards another charged body as soon as the

potential gradient is steep enough to overcome the resistance between them. The determining factors are the potential gradient and the insulating medium, which in this case is the air; and discharges can be caused either by increase in potential gradient, or by decrease in the resistance of the air, or by both.

Discharges take place more frequently between different portions of the same cloud than between different clouds or between a cloud and the earth, because within the cloud the air becomes ionized by point discharges from drawn-out water-drops, and so creates a path for the discharge.

The lightning-flash is the visible effect of the passage of the discharge. As it makes its way through the air intense ionization takes place along its course. Almost simultaneously the ions and electrons recombine, and in doing so emit light, and at the same time the sudden expansion and recoil of the heated air set up the vibrations that constitute thunder.

Thunder is not actually a prolonged sound but an explosion that is instantaneous with the flash. The prolonged effect is due to the speed at which sound travels, which is, comparatively speaking, slow. Light travels at 186,000 miles per second, sound at one mile in five seconds. The lightning-flash is generally several miles long, but nevertheless appears almost instantaneous. The explosion that causes the thunder

takes up the same amount of time, but it appears to spread over several seconds. At the speed at which sound travels the difference of a few miles between the beginning and the end of a flash makes a difference of several seconds between the arrival at any point of the sound of the explosion at one end and that of the explosion occurring almost at the same time at the other end, and so produces a continuous roll, starting from the nearest point and continuing along the course of the flash. To this is sometimes added the sound of echoes coming from still farther away. There is no cause to be afraid of thunder, for long before it reaches the ear the events that caused it are over. It would be as reasonable to be afraid of events over and done with before the issue of yesterday's newspaper.

Lightning, as is shown in photographs taken with a cinematograph camera, is always ribbon shaped and branched, never zigzag, as it is frequently pictured. Sometimes one apparently continuous discharge is made up of a number of separate strokes, as if there were breaks in the continuity of the supply of current by the cloud.

When lightning passes through a cloud, as it does in the majority of thunderstorms, or from one cloud to another, there can be no danger to the earth. About once in every four flashes, however, the dis-

charge takes place between a cloud and the earth, and on these occasions storms are not only awe-inspiring, as they must always be, but dangerous to life and property. A brief explanation of the manner in which the charge distributes itself over charged bodies will show where the danger lies.

If a charge is given to a spherical body, such as a soap bubble, it will distribute itself evenly over the surface as long as no other charged body is in the neighbourhood. If a sphere holding a charge of like sign is brought into the neighbourhood the effect of the repulsion between charges of like sign will be to distribute the charge so that it is more intense on the portions of the spheres that are farthest away from each other. If spheres holding charges of opposite sign are brought near together, attraction between the charges will cause them to be distributed so that the charge is more intense on the portions of the spheres nearest to each other. Again, if a charge is imparted to a long conducting rod, the force of repulsion between the particles that form the charge will cause most of them to crowd towards the ends of the rod. If the conductor tapers more at one end than at the other, the charge will crowd towards the tapering end, again because of mutual repulsion between the particles themselves. If this extremity is sharply pointed the concentration of charge may be so great that the

surrounding air becomes ionized and a discharge takes place. Discharges of this kind are known as 'point' or 'brush' discharges. When they are sufficiently intense they produce a purplish glow that in the darkness of a stormy atmosphere has the appearance of blue flames dancing upon exposed points. Sailors know it as Saint Elmo's fire. Ariel knew all about it, and recounts triumphantly

I flam'd amazement: sometime I'd divide
And burn in many places; on the topmast,
The yards, and bowsprit, would I flame distinctly,
Then meet, and join: Jove's lightnings, the precursors
O' the dreadful thunder-claps, more momentary
And sight-outrunning were not.

It was a terrifying apparition that sent the landlubbers diving, desperate, into the sea. But the mariners knew it of old, and Ariel or no Ariel were content to stay stowed under hatches and await events. It was a clever trick, whether Ariel or Shakespeare conceived it.

A charged cloud induces a charge on the surface of the earth beneath it by attracting particles of opposite sign, and this concentrates on any upstanding point, such as chimney-stack or steeple or tree. When the concentration is sufficiently intense the surrounding air becomes ionized and creates a path along

which a discharge will take place as soon as the potential gradient is steep enough. Exposed objects are more likely to be struck by lightning than flat surfaces, and during a thunderstorm the potential gradient may be so steep that the object needs neither to be very pointed nor to project very high above the ground to act as a discharger. A horse in a meadow, a tent pole, a human being, a solitary tree may concentrate sufficient of the earth's charge to act as a conductor.

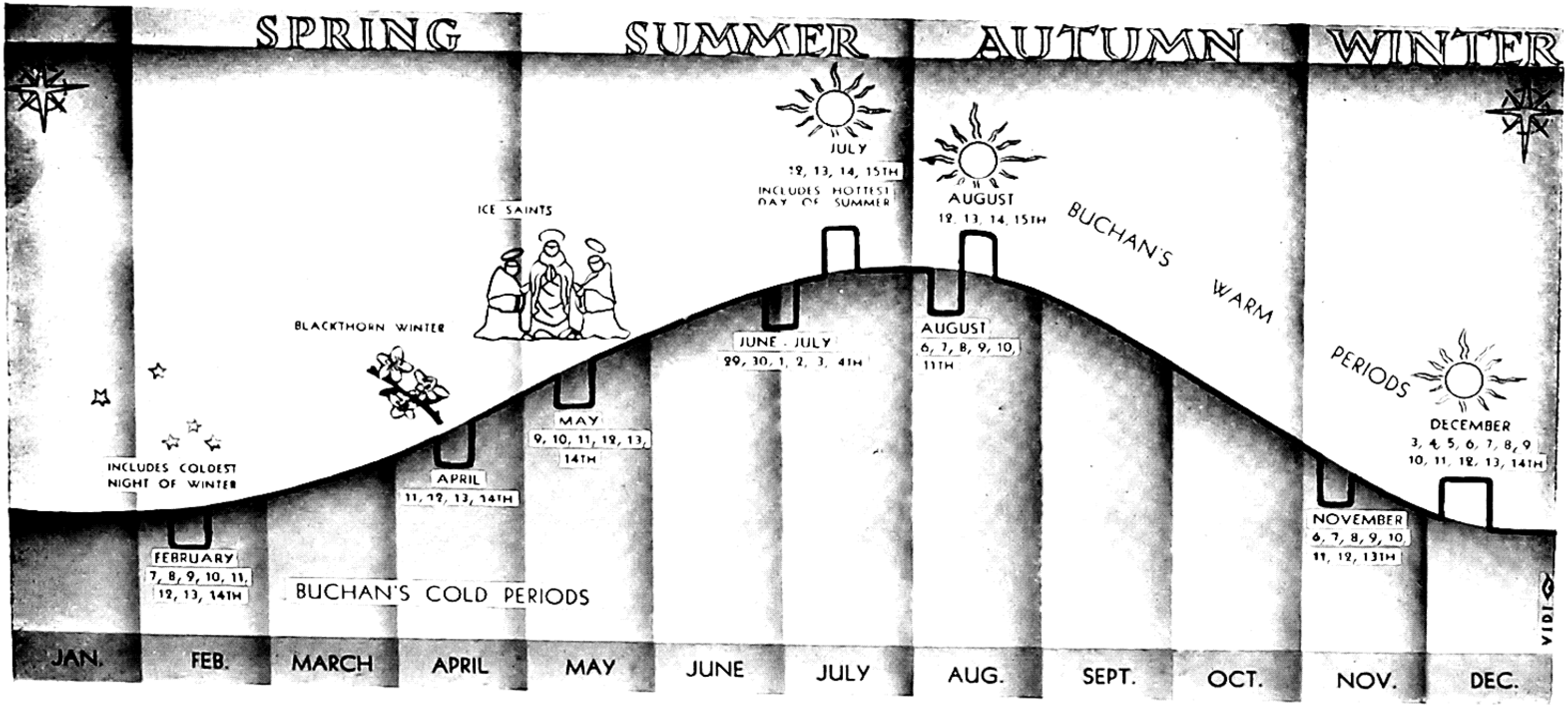
A lightning conductor acts as a protection both by attracting the lightning to itself and conducting it harmlessly to earth, and also—and this is of even more importance—by reducing the potential gradient by means of brush discharges. If it is to be an effective protection it must be very sharply pointed and must jut out well above all neighbouring objects.

It is commonly and correctly stated that thunderstorms are less dangerous when accompanied by rain. The reason is that each charged raindrop carries a certain amount of electric charge from the cloud to the earth, and so gradually reduces the potential gradient. For the same reason there is less danger towards the end than at the beginning of a storm, especially if the rain has been heavy.

The average quantity of electricity carried by a lightning stroke is about 20 coulombs, and the aver-

age value of the current must be of the order of 20,000 ampères. Lightning discharges have been recorded carrying currents of as much as 250,000 ampères. As a rule a single flash completely discharges the cloud, and as a cloud of average activity produces a flash about every twenty seconds the processes at work within the thunder cloud must be capable of generating electricity at the rate of one coulomb per second.

In the comparative placidity of temperate climates thunderstorms seem to be comparatively rare events, but they are not quite so rare as they seem if a large area is taken into consideration. In France, for example, there are few days when thunder is not reported. Over the whole earth's surface it is estimated that there are about 16,000,000 thunderstorms per annum, an average of 44,000 per day. If an hour is allowed as the duration of each storm there must be something like 1,800 storms going on simultaneously, providing about 100 lightning flashes per second, or 360,000 per hour. It must be admitted that electricity, even in its ostentatious manifestations, is a commoner phenomenon than is generally supposed.



BUCHAN'S WARM AND COLD PERIODS

XI

THE WEATHER PROPHET

The nineteenth century discovered scenery, but the benefit of the discovery was confined to an exclusive and self-conscious class. The twentieth century has discovered the open air, and it is the people, happier in this than their predecessors, who have taken possession. Weather has consequently regained a universal importance that it has not enjoyed since houses became watertight. The necessities of aviation have stimulated meteorological research, and weather forecasting has been raised from its doubtful association with quacks and fortune-tellers to the dignity of a science. But some traces of its old associations remain, and weather prophets are still more numerous

than meteorologists. To distinguish between the true and the false prophet something must be known of the foundations upon which prophecy may justifiably be based.

Weather forecasting falls into two categories, forecasting for a few hours ahead, as in the daily weather forecast, and forecasting for long periods of time. The first is dependent for its material on ascertainable conditions in the lower atmosphere. It is forecasting in the strict sense of the word, calculating beforehand. This will be dealt with in conjunction with weather maps in the next chapter. The second requires an understanding of the general circulation of the atmosphere such as, at present, appears almost beyond human attainment. It falls into the more doubtful category of prophecy, a foretelling of events not from calculation but from inspiration. But inspiration is not quite the only resource even of the weather prophet. The major arbiter of weather is indeed beyond his comprehension, but there are minor influences at work that can be studied with profit.

The moon is not one of these. Sailors believe that the weather alters with the changes of the moon, and sailors as a rule know what they are talking about. But not in this case. It is true that its gravitational pull attracts the air as it attracts the waters of the earth, and even the crust of the solid globe itself.

Tides are a reality in all three, but the consequent increase in atmospheric pressure is no more than 0·13 of a millibar, or at most 0·26, too small an amount to have any affect.

There are from the practical point of view only two influences on the weather that at the present state of our knowledge warrant serious attention in forecasting over long periods. The most talked of (the moon being left out of account) is that of sun-spots. They have inspired as many prophecies as the moon, but with more justification. If the prophecies have often been unfulfilled it is not because no facts are there to be interpreted but because interpretation presents such a puzzling problem.

Sun-spots are not completely understood. As seen from the earth they are irregularly shaped black spots surrounded by an area less darkly shaded known as the penumbra. The activities in the sun that give rise to them appear to be something in the nature of violent volcanic eruptions, increasing and decreasing in intensity over a period that covers on an average about eleven years and one month. The cycle is not very regular. It may cover as few as eight or as many as fourteen years. Nor are the periods of increase and decrease evenly divided, for the increase usually occupies about four and a half years, the decrease about six years and a half.

When the activity is at its maximum various phenomena occur on and about the earth, for the most part of an electrical nature. Polar Lights are at their greatest profusion, the transmission of radio waves is frequently interrupted, the earth's magnetic field is disturbed, the compass becomes erratic, and the quantity of ozone in the atmosphere increases. Here we touch the fringe of the subject of weather, for, since ozone absorbs a large amount of short-wave radiation, any increase in quantity must affect the nature and amount of the radiation that reaches the earth.

All these happenings may reasonably be attributed to showers of charged particles belched forth from explosions in the sun. It seems certain that during periods of sun-spot maxima the radiation actually emitted by the sun is increased, but at the same time the density of the sun's atmosphere appears to be increased, just as, in times of violent volcanic eruptions the density of the earth's atmosphere is increased, and since the sun's rays must traverse this atmosphere at the commencement of its interstellar journey the radiation that actually reaches the earth is less than average. As sun-spots increase the average temperature of the earth decreases, or to put it paradoxically the hotter the sun the cooler the earth, and vice versa.

But this is only the beginning of the paradox, for more solar radiation does not necessarily involve warmer weather, at least not in every season and in every latitude. An increase in solar radiation during sun-spot minima causes a slight increase in temperature in the torrid zones, but this same increase of temperature causes an increase of evaporation, i.e. of cloudiness and of rain. A rainy summer in temperate latitudes means a decrease in the amount of solar radiation that actually reaches ground-level, and therefore a decrease in temperature. The decrease in radiation accompanying sun-spot maxima has also a paradoxical effect in temperate zones, for a decrease in radiation involves an increase of pressure. In late spring and in summer high-pressure areas generally bring a dry atmosphere, clear skies, more sunshine, and on the whole, warmer days; but as soon as the sun has set the temperature falls. The night frosts of last year's spring as well as the spring drought may well be laid at the door of sun-spots. It was unfortunate for the weather prophets that they foretold a warm summer to follow, for in London at least the prophecy proved vain.

Taking the mean temperature over the whole earth the gain and loss appear to result in a slight decrease in temperature in years when sun-spots are most numerous.

Odd bits of historical evidence are quoted in support of the theory of the influence of the sun-spot cycle. Famines in India, which are due to drought, have occurred at intervals of approximately eleven years; measurements of the varying levels of Lake Victoria Nyanza also support the theory. Perhaps the most interesting evidence of all is brought forward by Professor A. E. Douglas, of the University of Arizona, who has discovered a correspondence between sun-spot activity and the rate of growth of trees. It is well known that the age of a tree can be calculated from the number of rings in a transverse section of its trunk, and that the rate of growth in any particular year can be gauged by the width of the ring formed. Professor Douglas has made an extensive study of trees cut down in Arizona and California, both of those recently felled and of those felled in the more distant past, and, reckoning backwards from the present time over several hundreds of years, he finds considerable evidence for the eleven-year cycle in growth, the period of abnormal growth corresponding with the period of sun-spot maxima. During the years 1645 to 1715 this evidence was lacking, and it subsequently transpired from the examination of astronomical records that during this period there was an unusual dearth of sun-spots.

Whilst giving due weight to this type of evidence

it must be remembered that much of it depends on records made at a time when instruments were very imperfect. Accurate records of sun-spot numbers and of annual temperature variations are available only since the year 1749. The records covering the hundred and eighty odd years from that time until the present bring to light with astonishing consistency another influence that has had a more marked effect on weather than, according to the same records, sun-spots have exerted. This is the influence of large volcanic eruptions upon temperature.

When temperature curves are studied in conjunction with the dates of eruptions there seems little doubt that there is a connection between the two. Volcanic dust hurled upwards by eruptions of great magnitude drift about in the upper atmosphere long after the eruption has occurred. These clouds of dust must absorb a large quantity of solar radiation and so cause a decrease of temperature on the earth's surface. To quote recent examples, the cold years of 1912 and 1913 coincide with the eruption of Katmai in Alaska on 6th June 1912; those of 1902, 1903, and 1904 with the eruption of Pelée, Martinique, on 8th May 1902, followed by that of Santa Maria, Guatemala, on 24th October 1902, and of Colima, Mexico, in February and March 1903. The years 1890, 1891, and 1892, when the frost was so severe that an ox was

roasted on the frozen Thames, are connected with two eruptions, that of Bogoslof, in the Aleutian Islands in February 1890, and that of Awoe, Great Sangir, on 7th June 1892. Those of us who can remember the eruption of Krakatoa on 27th August 1883 may also have vague recollections of the three severe winters that followed. The eruption of Krakatoa was the greatest since, a century before, Asama had erupted in Japan. This was the most terrible on record, and its dust cloud, reinforced by the eruption of Skaptar Jökull in Iceland on the 8th and 18th of June in the same year, and of Vesuvius in 1785, brought the three cold years of 1784, 1785, and 1786. We are all familiar with the fact that Napoleon's débâcle in Russia was made more catastrophic by the severity of the winter of 1812. Would he have chosen that autumn for his campaign if he had known that on the 30th of April of that year the volcano of Soufrière, St. Vincent, had erupted and that its dust-cloud was already casting its shadow over him? But the knowledge would have been of little value to him, for the winters of 1813, 1814, and 1815 were little less severe, and the year 1816 was still worse, for it was cold the world over. That was the year that became known as 'the year without a summer', 'poverty year', and 'eighteen-hundred-and-froze-to-death'. It is not without significance that in 1814 an eruption of consider-

able magnitude had taken place in Mayon, Luzon, and that in the following year the volcano of Tomboro, in Suwamba, was in violent and almost continuous eruption from the 7th to the 12th of April. This eruption was responsible for a death roll of 56,000, and its dust-cloud turned daylight to darkness for three days at a distance of three hundred miles. It is interesting to note that since 1912 no eruptions of unusual magnitude have occurred, nor any winters of abnormal severity.

When sun-spot numbers are studied together with the records of eruptions the significant fact emerges that during the severe seasons that have been quoted sun-spots were not numerous. Temperatures should accordingly have been on the whole above the average rather than under it. Volcanic eruptions appear to be the more dominating influence, and weather prophets should take due note of them. But when all has been said that can be said, it must be admitted that the weather prophet, when distinguished from the weather forecaster, must base his predictions on very slender material. It is no wonder that he sometimes falls back on statistics.

Statistics have a way of arousing extreme feelings. Their advocates say that they cannot lie, their antagonists hotly declare that they always lie. Where weather is concerned they merely record some inter-

esting facts that are quite insufficient for purposes of prophecy. When they have been kept for several hundreds of years more they may show more definite indications than they do at present. Nevertheless they have their charm, and it is not lost on a nation that prefers to give to gambling any other name.

One of the great achievements of statistical study of weather was made by the brothers Chandon, who between them kept a record of rainy days at Montdidier during the years 1784 to 1869. During this period of eighty-six years the days on which rain occurred most frequently, i.e. on one day out of two, were:

January 20, 30
April 23
May 13
July 24
September 22, 23, 24
October 8, 18
December 2, 4, 6, 17, 27

Days on which rain occurred on an average on one day out of three during this period were:

February 5, 18
March 17, 26, 27, 29, 30
April 19
May 5, 19, 21, 24
June 12, 14, 24, 28

July 10, 11, 13, 14, 16, 22, 31
August 1, 2, 11, 25, 27
September 2, 9, 12, 13, 15, 16, 17, 26
October 13, 20, 21, 23
December 7, 10

The rainiest day of all was the 23rd of September, which was wet forty-eight times out of a possible eighty-six, and the finest day was the 11th of August, on which it rained only nineteen times. Whether it is possible to argue from these figures that there is a 56 per cent chance of a wet 23rd of September and a 78 per cent chance of a fine 11th of August is doubtful. An abnormally long life might be necessary to make good the losses, and during that period local climate might change. In any case the figures apply only to Montdidier.

Sir Napier Shaw made a similar study of the frequency of gales over the British Isles during a period of twenty years, and a more widely known survey of existing records was made on the subject of temperature by Alexander Buchan. This survey is the origin of the notorious Buchan's cold spells that are paraded in the daily press for our consolation when summer is carrying on one of her unwelcome flirtations with winter. His warm periods are rarely mentioned, perhaps because they are too pleasant to require an explanation.

In his comparison of temperature charts Buchan noticed that between the coldest period of the middle of January and the hottest period of the middle of July temperature showed certain well-marked fluctuations in its gradual increase and decrease. After the slight expected increase towards the end of January there was frequently a marked fall about the second week in February; temperatures in the following month progressed on the whole as the march of the sun dictated, but April, May, and June showed frequent setbacks before the warmest period of the middle of July was reached. Again, after the expected drop towards the end of that month, continued during the first fortnight of August, the middle of August often showed a sudden rise. Again, in December the increase of cold gave place to ten days or so of milder weather before the coldest period of the year set in.

As has already been remarked, it is not possible to argue that because interruptions have occurred in the annual rise and fall they will continue to recur at the same dates, but all the same it is comforting when we find ourselves shivering towards the end of June to remember that the same thing has happened many times before and summer has yet reappeared before the month was out. It is for this very human reason rather than for their doubtful value in prevision that the complete list of these periods is given.

It is amusing to note that the cold period of May falls at the same time as the fêtes of the Saints of Ice, Mamert and Pancras, on the 11th of May, with Gervais somewhat premature on the 19th of June. Saint Luke and Saint Martin, on the other hand, fail to establish any claim to a Little Summer either near 18th October or 11th November. If our own Saint Swithun were to look for support to the records of the brothers Chandon he would find that even if his own fête, 15th July, were wet he could still reasonably expect only seven wet days out of the traditional forty, and of course, only at Montdidier. Saint Médard, the French Saint Swithun, whose fête falls on the 8th of June, has a fair chance of three more—but then he is French.

XII

WEATHER MAPS AND THE WEATHER FORECAST

It is reassuring to be able to come down from the nebulous realm of the weather prophet to the more concrete facts upon which the weather forecaster bases his cautious predictions. These consist of observations, collected from all available sources and rendered as exact as possible by reference to an accepted standard, of meteorological phenomena such as pressure, temperature, wind, state of the sky, precipitation, lightning and thunderstorms, mists, fogs, and vaporous conditions in the atmosphere, ground phenomena, such as dew, frost, etc., and optical phenomena such as rainbows, haloes, etc. From this

information large and detailed weather maps are prepared at the Meteorological Office, and sections of the complete map are issued twice daily by the press. These vary in size according to the importance attached to them by the journal in which they appear, but even the most detailed are far too small to contain all the information available, and a selection is therefore made of the most significant features.

Weather maps are not difficult to interpret. Barometric readings are given in millibars, and in several journals a table is included that gives the equivalent in inches of mercury. In maps issued by the British Meteorological Office temperature is still given in degrees Fahrenheit, but the tendency towards internationalism in scientific terminology that inspired the adoption of the millibar will no doubt before long result in the adoption of degrees Centigrade. Force and direction of the wind are shown by the arrows of the Beaufort Scale, the number of barbs giving the force, and direction being towards the station from which the observation is made. The state of the sky and precipitation in its various forms are shown by letters. These in the majority of cases are the first letter of the word indicated, e.g. *b* for blue sky, *c* for cloud, *r* for rain; but there are a few exceptions. Dew is indicated by its last letter, *w*, because the letter *d* has already been used for drizzle; *h* indicates hail, *z* haze,

and *x* hoar-frost. The complete list, together with the international symbols, is given in the table on pages 209–12. Small letters are used to indicate moderate intensity, capital letters to denote unusual intensity, and the small suffix $_0$ below the line to indicate slight intensity. Continuity is aptly conveyed by a repetition of the letter, and the letter *i* is prefixed to indicate that the phenomenon is intermittent. As the sky may be blue without being cloudless the two letters *bc* frequently occur in combination; *b* is used only where more than a quarter of the sky is clear, and *c* where more than a quarter of it is clouded; *o* is reserved for occasions when the sky is completely overcast.

The official weather forecast is prepared from the detailed reports at the head office, but it is not concerned with the actual time at which these reports are made. The morning (7 a.m.) weather map furnishes the material for the forecast published in the evening papers, and the evening (6 p.m.) weather map for that published in the morning papers.

The forecaster is faced with four major problems. First, what type of weather is associated with the prevailing pressure distribution? Secondly, in what direction are the pressure systems likely to move? Thirdly, how will they develop as they move? And fourthly, what will be the influence of local geographical conditions?

BEAUFORT LETTERS AND INTERNATIONAL SYMBOLS[1]

1. Appearance of Sky

Beaufort Letter	*International Symbol*	
b		Blue sky, whether with clear or hazy atmosphere
c		Cloudy, i.e. detached opening clouds
o		Overcast, i.e. the whole sky covered with one impervious cloud
g		Gloom
u		Ugly, threatening sky

2. Wind

—		Gale (Force 8 or above)
q		Squalls
Q		Heavy squalls
q_o		Light squalls
KQ		Line squall

3. Precipitation

r	●	Rain
R	$●^2$	Heavy rain
r_o	$●^\circ$	Light rain

[1] It will be noticed that several of the International Symbols in the code are given more than one meaning. This is due to a recent revision and extension of the Beaufort Code which has made possible a greater precision of description than can be achieved when the International Symbols are used.

3. PRECIPITATION—*continued*

Beaufort Letter	*International Symbol*	
rr	●	Continuous rain
RR	$●^2$	Continuous heavy rain
$r_o r_o$	$●^o$	Continuous light rain
p	●	Passing showers
P	$●^2$	Heavy passing showers
d	●	Drizzle
D	●	Thick drizzle
d^o	$●^o$	Thin drizzle
dd	●	Continuous drizzle
DD	●	Continuous thick drizzle
$d_o d_o$	$●^o$	Continuous thin drizzle
s	$*$	Snow
S	$*^2$	Heavy snow
s_o	$*^o$	Light snow
ss	$*$	Continuous snow
SS	$*^2$	Heavy and continuous snow
$s_o s_o$	$*$	Light and continuous snow
rs	$*$	Sleet
RS	$*^2$	Heavy sleet
$r_o s_o$	$*^o$	Light sleet
rs rs	$*$	Continuous sleet
RSRS	$*^2$	Heavy and continuous sleet
$r_o s_o r_o s_o$	$*^o$	Light and continuous sleet
—	Δ	Soft hail

3. PRECIPITATION—*continued*

Beaufort Letter	*International Symbol*	
h	▲	Hail
H	▲²	Heavy hail
h_o	▲°	Slight hail
hh	▲	Continuous hail
HH	▲²	Heavy and continuous hail
h_oh_o	▲°	Slight and continuous hail

4. ELECTRICAL PHENOMENA

t	T	Thunder
l	↯	Lightning
tl	T↯	Thunderstorm
TL	T↯²	Severe thunderstorm
t_ol_o	T↯°	Slight thunderstorm
tltl	T↯	Continuous thunder and lightning

5. ATMOSPHERIC OBSCURITY, SUSPENSOIDS, AND WATER VAPOUR

f	≡	Fog	Range of visibility less than 1,100 yards
fe	≡ ⁝	Wet fog	
z	∞	Haze. Range of visibility 1,100 yards or more, but less than 2,200 yards	
z	∞°	Haze. Range of visibility more than 2,200 yards	
m	≡	Mist. Range of visibility 1,100 yards or more, but less than 2,200 yards	
	S̶	Dust or sand-storm	

5. Atmospheric Obscurity, Suspensoids, and Water Vapour—*continued*

Beaufort Letter	*International Symbol*	
	←	Ice crystals in the air
		Drift snow
v	0	Abnormal visibility
e		Wet air, without rain falling
y		Dry air (less than 60 per cent humidity)

6. Ground Phenomena

w		Dew
x		Hoar-frost
	V	Rime
		Glazed frost
		Snow lying

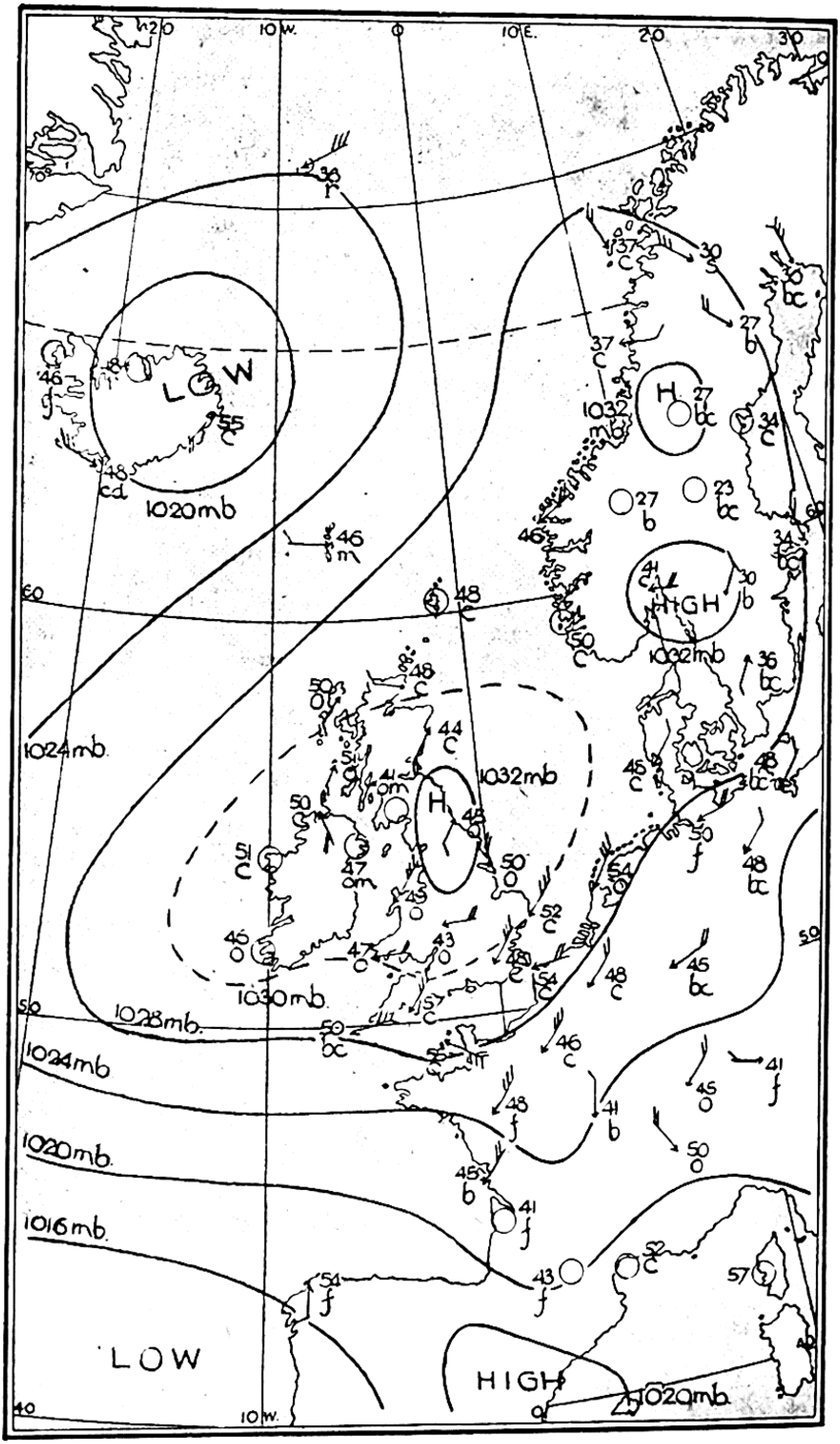
7. Optical Phenomena

	Solar corona
⊕	Solar halo
	Lunar corona
	Lunar halo
	Rainbow
	Aurora
	Zodiacal light
	Mirage

The solution of these problems is not to be reached by mathematical calculations, and therefore it can never be an exact and infallible solution. Experience and keen observation go a long way towards success, and the remarkable fact about the official forecast is not that it is occasionally wrong but that it is so often right.

There is a general impression that good weather is always associated with anti-cyclones and bad weather with depressions, but this impression needs considerable qualification. So far as anti-cyclones are concerned it is true only when applied to the absence of rain, for in winter they generally bring fog and an overcast sky. The winds of a high-pressure system are much lighter than those associated with a depression, and fog once formed tends to linger. A pressure inversion is also characteristic of this system, and when it occurs a thick canopy of cloud is formed, which, although it rarely precipitates rain, is nevertheless very oppressive and unpleasant. When at the same time fog forms at ground level it may remain for a long period, for the absence of both wind and sunlight leave it master of the situation.

It is in summer that the anti-cyclone has acquired its good reputation. Even then it is not guiltless of fog, especially after clear nights, but the vertical sunlight is then strong enough to dissipate it before the



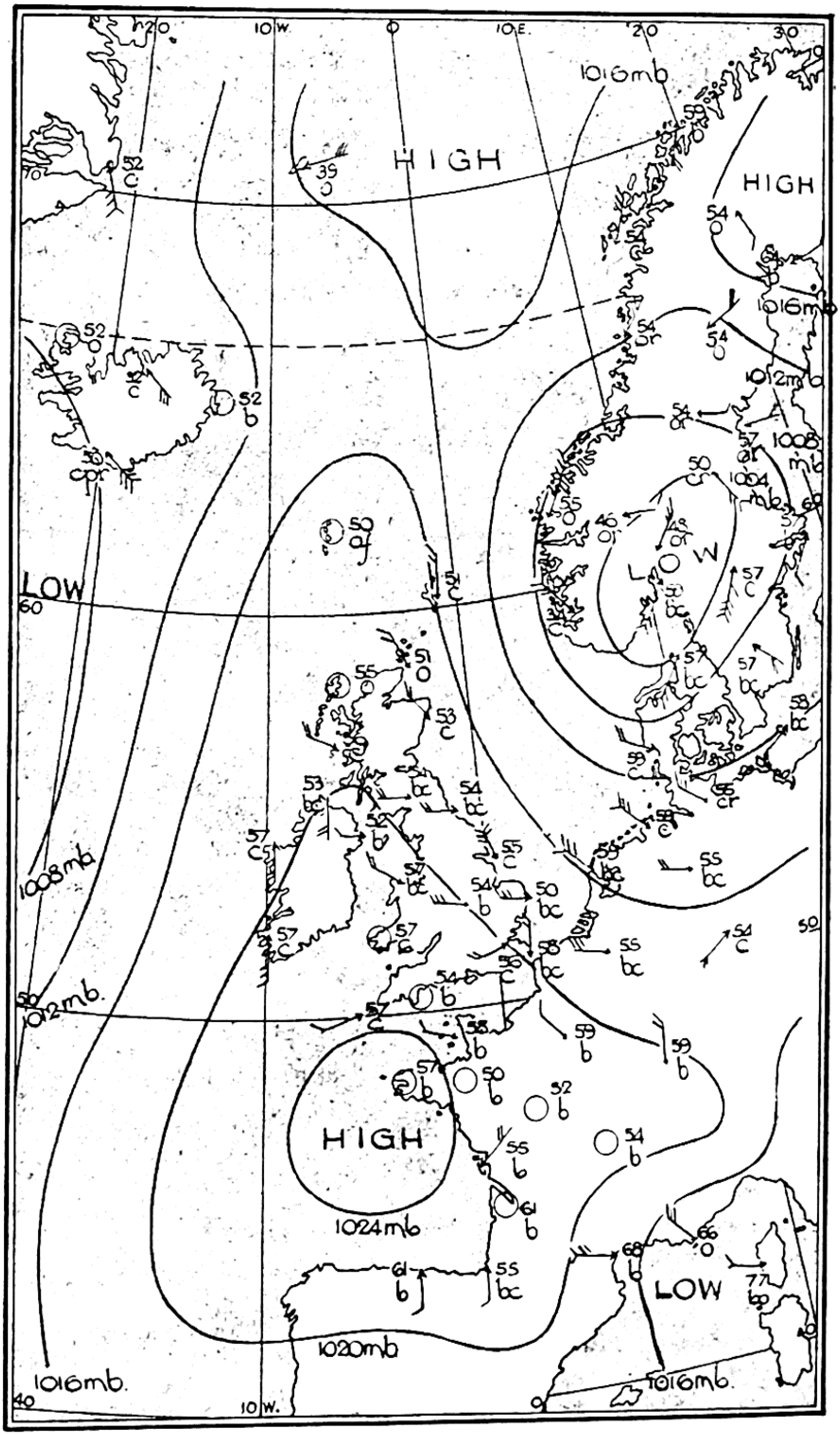
ANTI-CYCLONE
By kind permission of H.M. Stationery Office

morning has grown old. Rain is unlikely, for the cool current of air carries little water vapour, and the prevailing conditions are clear sky, continuous sunlight, and gentle breezes.

The map on page 214 shows a typical anti-cyclone centred over the British Isles during the month of October. It will be noticed that over most of England the sky is overcast, there is mist in eastern Ireland and over the west of Scotland, cloud over the Channel, fog at several European stations, and not a great deal of blue sky anywhere—not the popular idea of an anti-cyclone at all, but a correct one.

The fairest weather is usually associated with what is described in the forecasts as a 'wedge of high pressure'. In this system the isobars take the form of an inverted V with a somewhat rounded angle, on either side of which are situated low-pressure systems. A good example of this type is shown on page 216. It shows a preponderance of blue sky over England and France, and although the sky is overcast in the north of Scotland there is neither mist nor rain anywhere over the British Isles. The wedge has a way of moving off with what seems unnecessary haste, but whilst its influence lasts the weather leaves little to be desired.

The weather associated with depressions is more fickle, but it has marked characteristics, and as these follow a definite order that keeps pace with the



WEDGE OF HIGH PRESSURE

By kind permission of H.M. Stationery Office

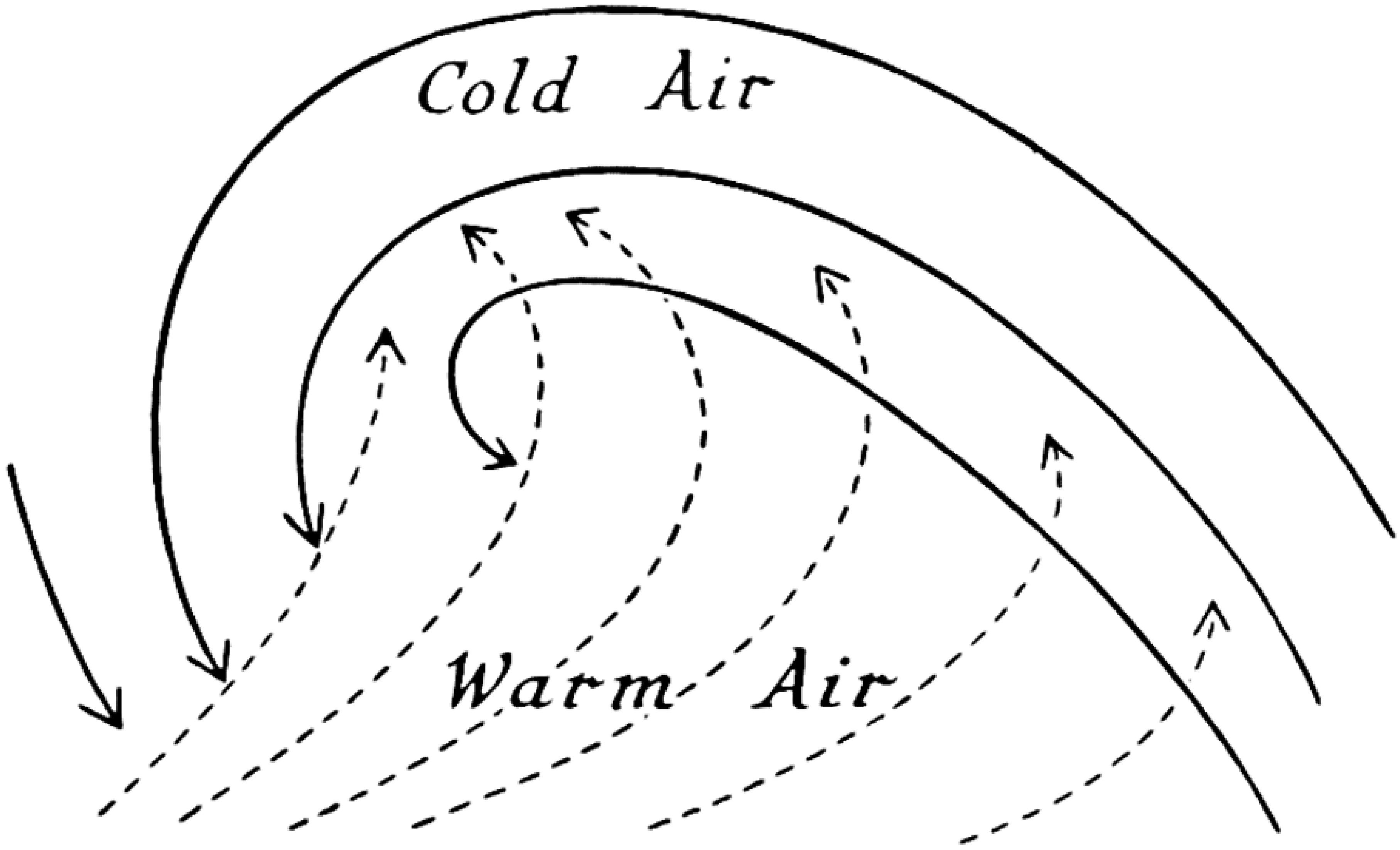
development of the depression this process merits some attention.

It is probable that depressions are formed where a warm air current is blowing in one direction, and in the opposite direction a cold air current is blowing alongside of it, like trains passing each other on the up and down lines. The warm current is called tropical air, and usually blows in a north-westerly direction; the cold current is called polar air, and usually blows in a south-westerly direction; the division between them is not vertical, but slopes gently towards the north, so that above the cold air, near the margin of the respective currents, warm air is blowing. As long as each current keeps strictly to its own course all is well, but it requires only the very slightest impulse to upset the delicate balance, and when this happens the warm air overflows and forms a bulge in the region occupied by the cold current. The bulge of warm air then starts to climb up over the heavier air of the cold current, and at the same time the cold current, blowing round it, begins to lift it up. The result is that the warm air forms a large promontory joined to the main warm stream by a rapidly narrowing isthmus. Eventually the isthmus is lifted off the ground and the warm air forms an island at ground level, which, high above the earth, is still connected by a bridge of warm air to the tropical current. The

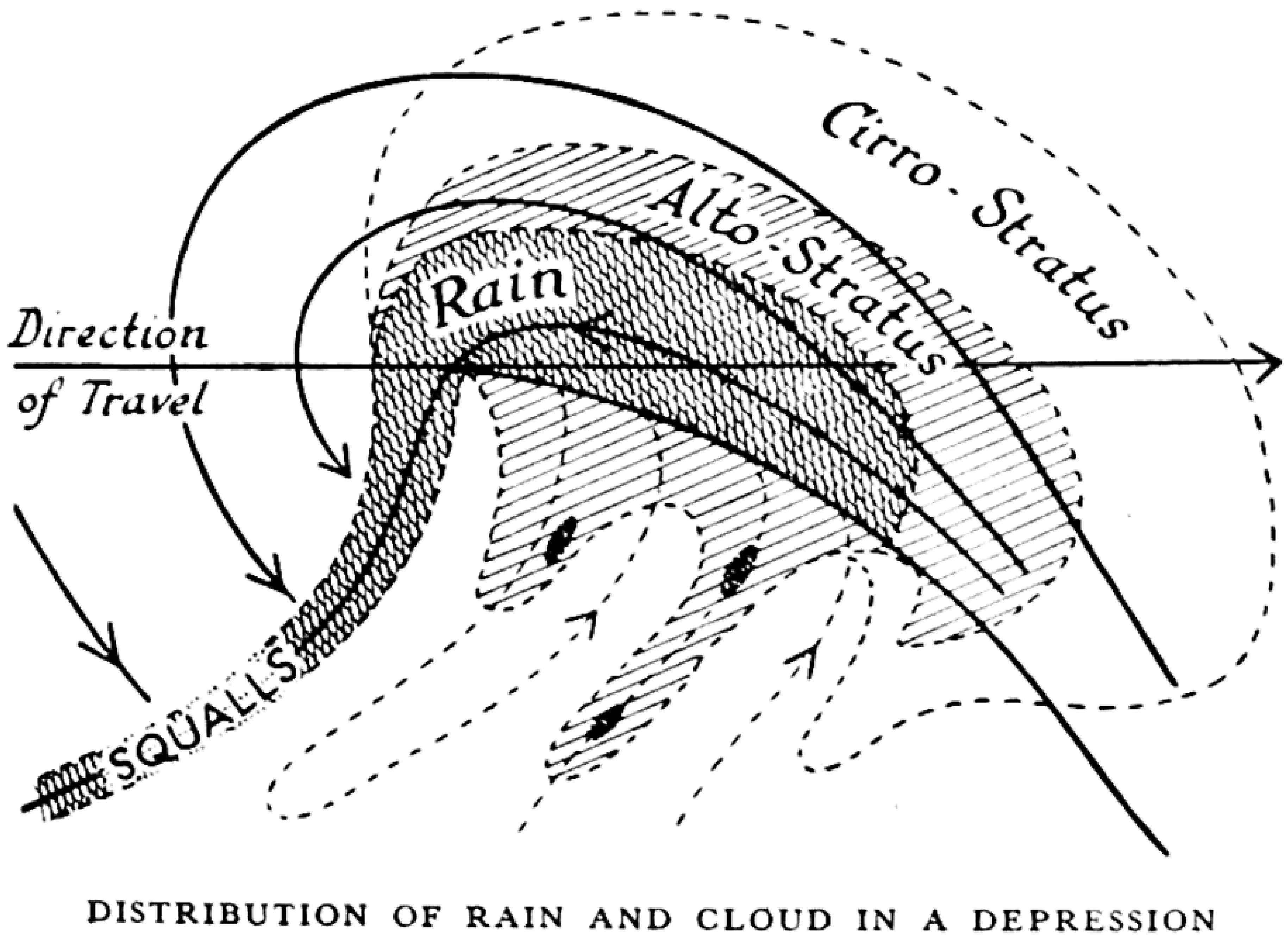
depression is then said to be 'occluded'. As it fills up, the island of warm air in the centre rises, and gives place at ground level to polar air.

Before the development of the depression had been intensively studied the Hon. Ralph Abercrombie had constructed from analysis of observed weather conditions a diagram of a depression and its characteristic weather that differs little from what later knowledge would have made it. The weather associated with a depression is very consistently what might be expected from the manner of its formation. At its forefront is the warm moist air that has already mounted high above the cold current, made manifest in the high cirrus clouds that herald its approach. These high cirrus, as the warm air spreads out across the sky, develop into cirrus haze, haloes are wont to appear, and the moon 'looks with a watery eye'. As the depression comes nearer the warm air becomes more abundant, it has not had time to climb so high, alto-stratus forms and hides the sun or moon completely. After a while the low nimbus clouds roll up and the rain begins.

In the very centre of the depression warm air extends from the ground upwards, the barometer is at its lowest, the atmosphere is warm, moist, and cloudy, but rain seldom falls in any great quantity. The passing of the centre of the depression is signalled by a



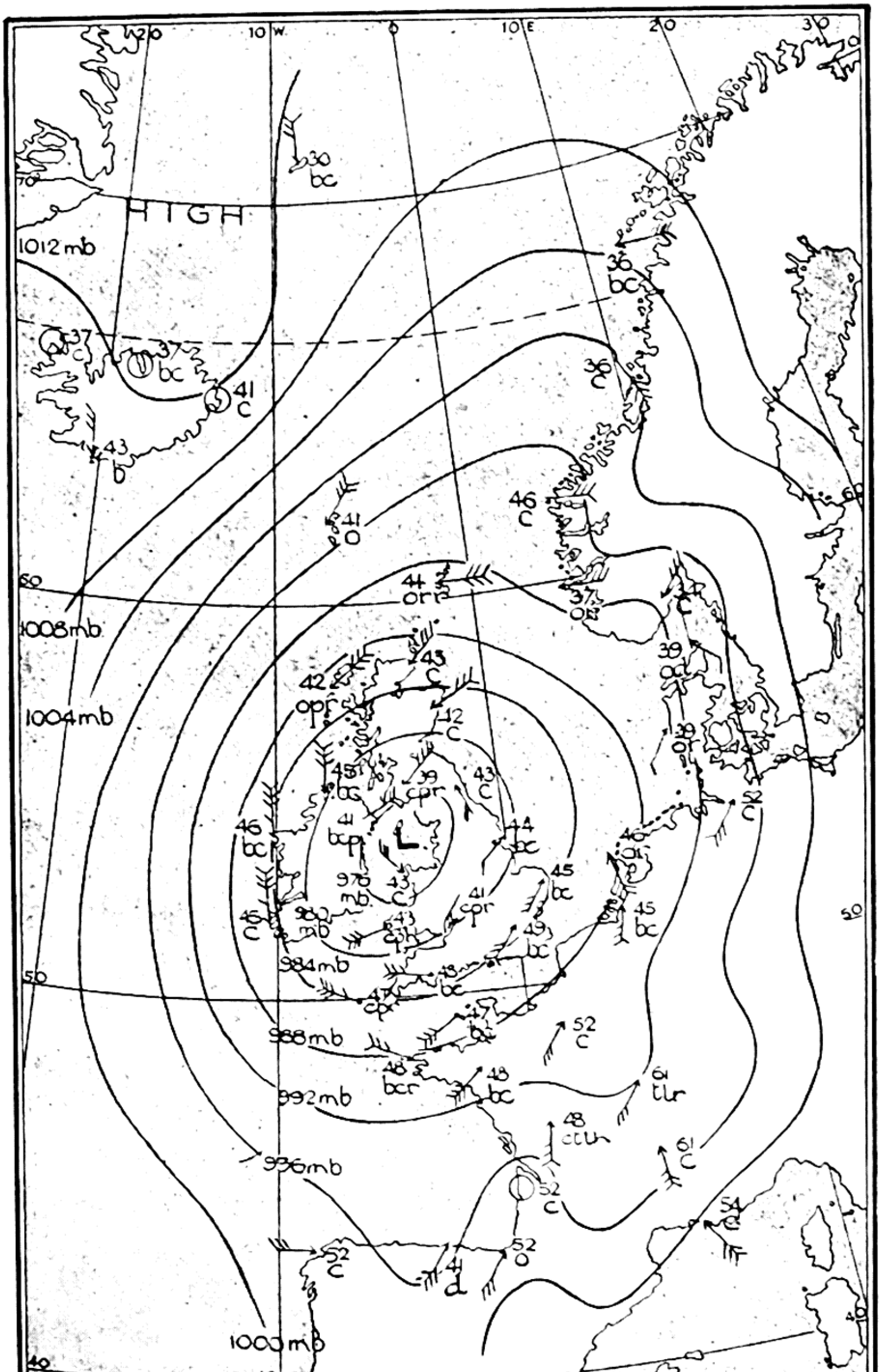
DIRECTION OF AIR CURRENTS IN A DEPRESSION



DISTRIBUTION OF RAIN AND CLOUD IN A DEPRESSION

rise in the barometer and a fall in temperature, for the cold air now occupies ground-level and has lifted the warm air to higher levels with such rapidity that rain falls in sharp heavy showers. The character of the rain in the rear of a depression is very different from that in its van. The reason is that the warm air, rising laboriously above the cold stream, climbs slowly, but is lifted rapidly when the cold current takes the initiative. As the depression continues its advance the moist air passes onwards with it, the layer of cold dry air becomes deeper, blue sky appears, cumulus clouds begin to form, showers become less frequent until they cease altogether, and the depression may be said to have passed.

The weather just described is characteristic only of the locality that lies in the direct line of the course taken by the depression, and during the earlier stages of its development before the warm air at its centre has been lifted off the ground. After the depression is occluded the conditions due to the huge pillar of uniformly warm air at its centre change to conditions similar to those farther in the rear where the cold current occupies the lower layers. The period of warm, cloudy air with little rain is omitted, and as the depression continues on its way the period of steady rain is immediately succeeded by the period of showers. As the majority of depressions that reach



DEPRESSION

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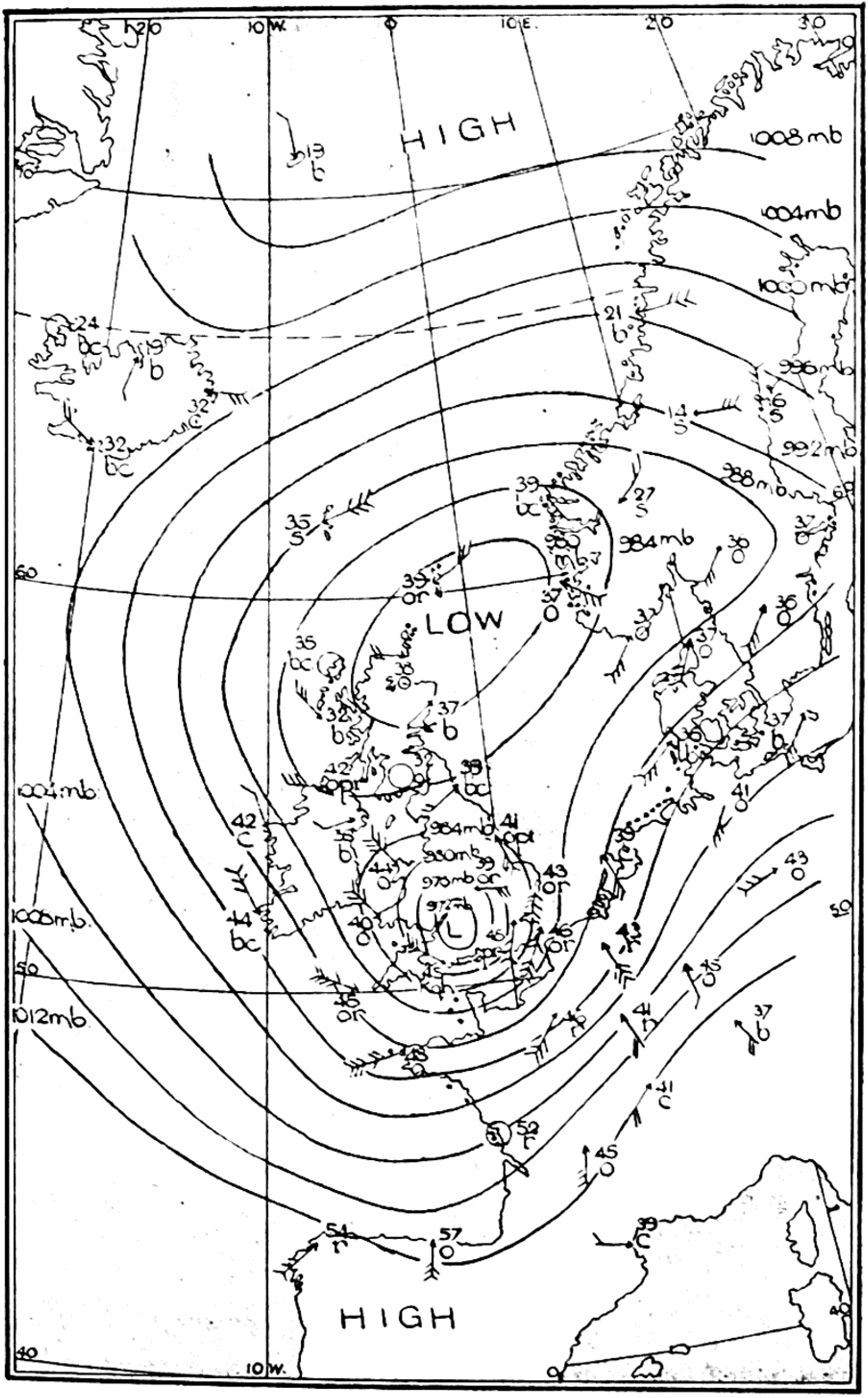
the British Isles are formed over the Atlantic they are generally occluded before they reach land, and the usual order of weather in their direct path is therefore cirrus, cirrus haze, altostratus, steady rain, showers, clearing showers. A fall in the barometer still indicates the centre of the system but it is not accompanied by a rise in temperature.

Weather in the outlying regions of a depression is more difficult to classify than weather in its direct path, and forecasting is therefore more uncertain. Its chief characteristic is cloudiness, first the high cirrus, then cirrostratus developing into a dense layer of cumulostratus, which breaks up into detached cumulus as the depression passes.

A depression frequently develops a 'secondary' within its sphere of influence, and the weather then to be expected is an intensification of all the most unpleasant features of the simple depression. The secondary may be anything from a slight irregularity in the isobars to a fully developed depression with an isobaric system of its own. It circulates in an anti-clockwise direction round the parent depression as the latter advances, and generally reaches its greatest development on its southern side. Its winds circulate as in a simple depression and reach their greatest violence in the quarter farthest from the centre of the main system. The gales that sometimes sweep



SECONDARY DEPRESSION

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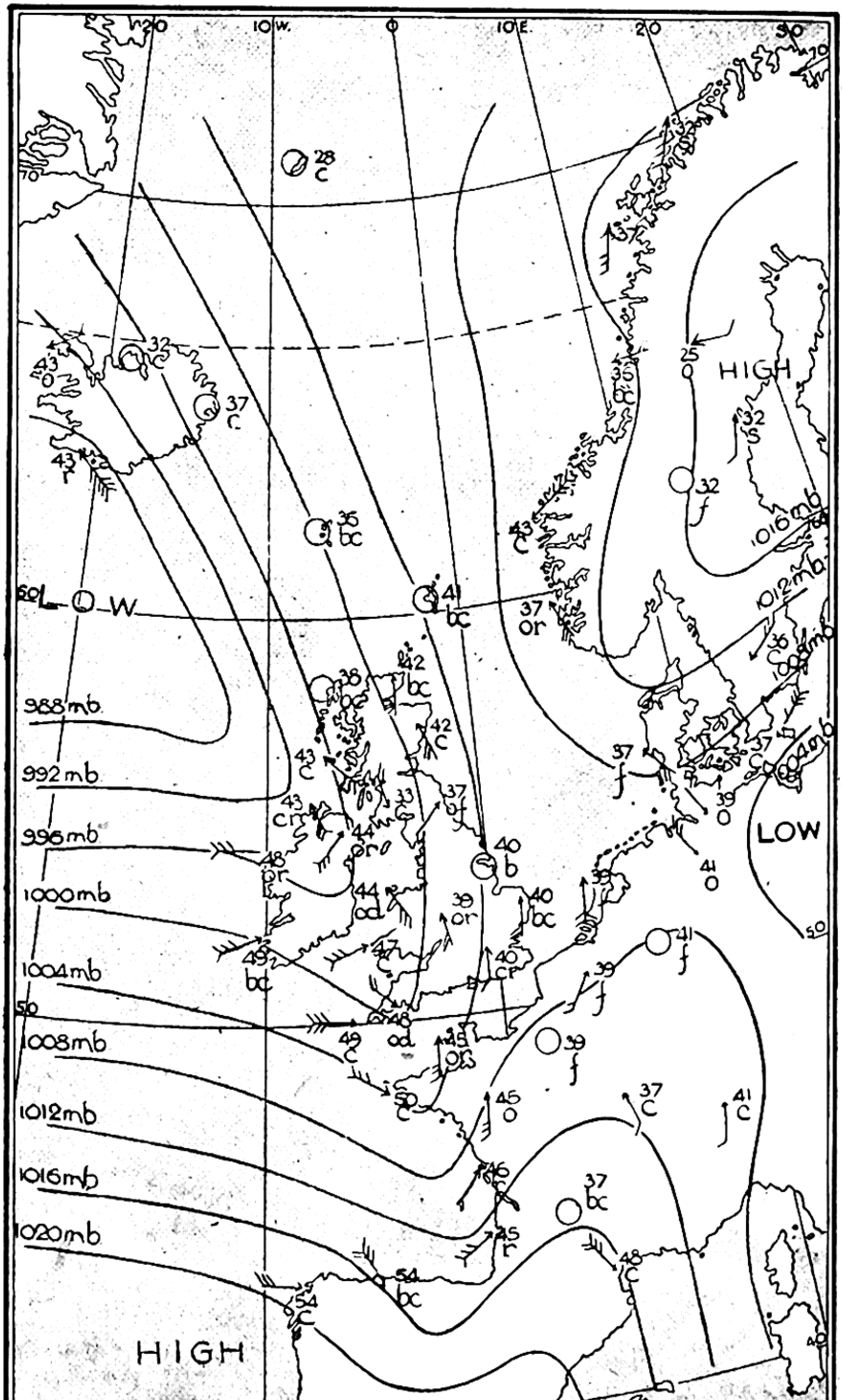
along the south coast of England owe their violence to a secondary that is travelling round a pressure system centred to the north of the British Isles.

A V-shaped depression is closely related to a 'trough of low pressure', and both are often mentioned in the weather report. The difference between them is that the isobars form a very sharp lower angle in the V, and in the trough the angle is more rounded. The difference in the weather they bring is that the veer of wind characteristic of both is more sudden in the former than in the latter. A veer in the wind is a change in a clockwise direction, as from east to south, or from south to west; backing is a change in an anti-clockwise direction. In both V-shaped depression and trough of low pressure, cold air is generally under-running warm air, and the result is sharp showers, clear skies, and a fall in temperature. Less frequently the weather resembles that in the van of a depression, i.e. persistent rain giving place to mild cloudy weather. When, as is usually the case when they are passing over the British Isles, the low-pressure system of which they form a part is already occluded, the weather characteristics are less marked, and the only noticeable effect they produce is in the veering of the wind and in an increase of cloud.

Sometimes, but not very often, an area of relatively low pressure is sandwiched between two depressions

and two anti-cyclones. This system is called a 'col' and is illustrated on page 228. It forms a convenient path for the advance of a depression and is therefore of short duration, but whilst it lasts it is a region of light winds, favourable to the development of fog in winter and of thunderstorms in summer. Apart from the light winds its weather characteristics are variable and difficult to predict.

In solving the problem of the probable movements of pressure systems the forecaster is guided by two main considerations. The first of these is barometric tendency, and it is of such great importance that even in the restricted space of weather maps published in the Press it finds a place. A depression is likely to advance along a line showing the greatest fall in pressure, and an anti-cyclone along a line showing the greatest rise. If the barometer shows no marked tendency then the forecaster must fall back on his second clue, his knowledge of the usual course pursued by pressure systems similar to the one in question. A fully developed depression generally travels in the direction of the isobars that cross its warm sector. Another consideration that the forecaster must bear in mind is the habit of well-established systems to persist. It sounds a ridiculous argument that because the weather has been unsettled for a fortnight it is likely to continue to be so, or that, since it has been



V-SHAPED DEPRESSION

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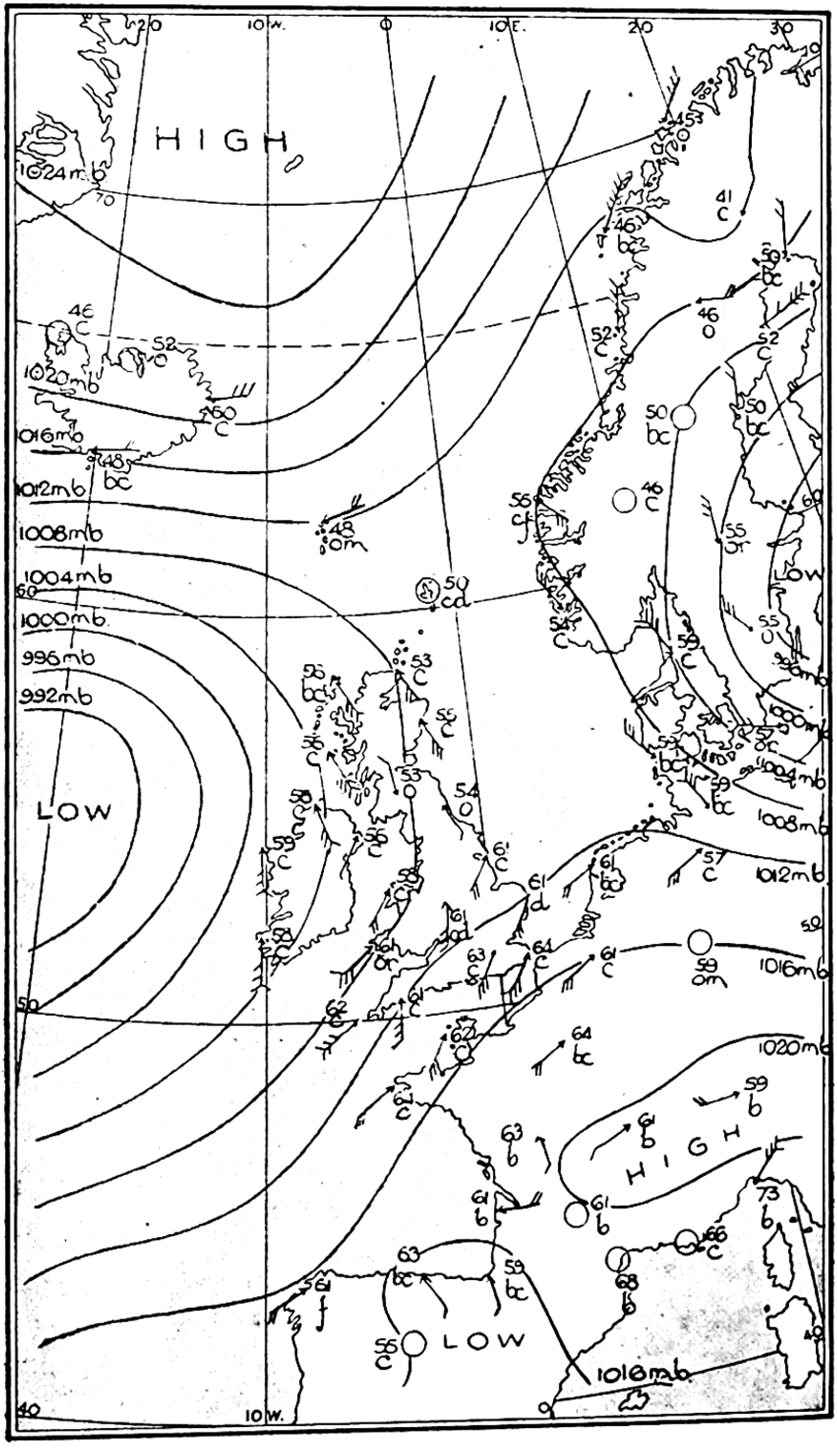
fine for three weeks it is likely to be fine for a fourth, but it is a cogent argument in weather forecasting, and is often used to resolve a doubtful riddle.

In forecasting the development of pressure systems it is essential to know what stage of development they have already reached, and in this connection reports from distant stations and from ships at sea are of invaluable assistance. In estimating the effect of geographical conditions more local knowledge is necessary, and to this local knowledge the principles laid down in the earlier chapters must be applied.

Enough has now been said to give some idea of the difficulties that face the forecaster and of his method of meeting them. To give a full account of either within the scope of a short chapter is neither possible nor desirable. The burning question to which every person really interested in the subject of weather wants some kind of answer is 'How can I tell whether it is going to be wet or fine to-day?'

It is by no means an absurd or unreasonable question, for although weather-forecasting over a large area and for a long period is difficult and uncertain, forecasting over a small area and for a few hours ahead is much more likely to achieve success. The weather-wise farmer originally had two sources of information only, the state of the sky and the direction of the wind, and yet he generally chose the right



COL

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day to carry his hay, and knew when the corn could safely be left in the field. Some animals betray an uncanny knowledge of approaching storms, and the knowledge can come to them only by way of their senses. It would be strange if the amateur forecaster, with all his additional knowledge, could not equal the prescience of farmer or bird.

There is no reason why he should not excel it. A keen observer becomes familiar with the behaviour of weather in his immediate neighbourhood, and if he makes a habit of comparing the official forecast with what actually happens he will come to know when it can be applied and when more local effects are to be expected. It is hoped that he will have found in this book some aid in the interpretation of these local effects, and will have kept in his memory the hints dropped here and there about weather signs.

One thing at least he can learn from the mechanical forecaster that is a combination of barometer, thermometer, and prophet. When it has been adjusted according to pressure, direction of wind, and barometric tendency the forecast appears engraved in a small space on the brass face of the dial. Sometimes two forecasts appear, and then the ensuing weather may be expected to be a mixture of both. The amateur forecaster may well take this lesson to heart. There is nothing safer than to supply the in-

quirer with an alternative, and in forecasting as in quarrelling there is much virtue in 'if'.

Above all things the amateur forecaster must learn to observe the sky. Like a human face it is inscrutable to the casual observer, but to those who watch it intently it will betray its mood sooner or later. Having learnt to observe it for purposes of forecasting he will continue to observe it for its own sake. The Psalmist found inspiration as he lifted up his eyes to the hills, and inspiration, for a generation much in need of it, is still to be found in contemplation of the sky. Study of the winds and the clouds and the rain, of sunrise and sunset and of the multitudinous lights in the sky, opens up a new realm, intimate and at the same time mysterious, having all the qualities that win the heart and intrigue the mind.

Weather has been likened to music, but who cares for music who hears a few notes here, a discord there, and turns away before the melody develops and the discord is resolved? Weather repays an intimate study independently of any acquired facility in forecasting, and interest in it, once awakened, does not fail. With its infinite variety it never stales. If it rains to-day it may clear to-morrow; if it vexes it does so that it may afterwards please the more. To weather as to human beings, the saying may be aptly applied, 'To know all is to forgive all'.

INDEX